National Aeronautics and Space Administration

Glenn Research Center Test Facilities

Message from the Director of Engineering and Technical Services

The mission of the National Aeronautics and Space Administration (NASA) is to understand and protect our home planet, to explore the universe and search for life, and to inspire the next generation of explorers. At the NASA John H. Glenn Research Center (GRC) at Lewis Field, we are a diverse team working in partnership with government, industry, and academia to increase national wealth, safety, and security, protect the environment, explore the universe, and develop and transfer critical technologies. These partnerships enable us to address national priorities through research, technology development, and systems development for safe and reliable aeronautics, aerospace, and space applications. The cutting-edge technologies developed at GRC enable powered flight through the atmosphere and beyond, thus promoting U.S. economic growth, national security and flight safety. Our premier ground test facilities and flight research capabilities support these research and development efforts that have uniquely positioned this Center to lead NASA and its partners in driving technological innovation forward into the 21st century.

We are home to 24 major test facilities and over 100 research and development laboratories located at our site in Cleveland, Ohio, and at our Plum Brook Station in Sandusky, Ohio. Our ground test facilities include the world's largest thermal vacuum facility, large aeropropulsion wind tunnels, engine test cells, flight research, and research and development laboratories. Our ground test facilities are available for use by our NASA research and development programs, other government organizations, industry, and academia.

We have made substantial investments in our ground test facilities in order to upgrade and modernize our capabilities. These investments have allowed us to improve our test performance capabilities, improve our cost effectiveness, and increase our efficiency. Our customer satisfaction metrics indicate that through these state-of-the-art enhancements, we offer ground test services that our customers perceive to be of excellent value.

We offer both test and evaluation and excellent research and development services, which combine our world-class facilities and research engineering capabilities. We are a full-service test engineering and operations service provider, starting with our highly trained and skilled staff of test engineers and technicians. Our research engineers and scientists are available to provide engineering and scientific knowledge and know-how to our many external test customers. Our engineering and technical services organization provides facility and test article design services, test article and test support equipment fabrication, and research instrumentation in support of our test customers. We are ISO9001 certified, thus ensuring a disciplined approach to test operations.

I hope that you find the material contained herein to be of interest and use to you in better understanding the ground testing capabilities of the NASA GRC. I encourage you to contact any of our facility managers, listed within this book, to learn more about our GRC test facilities and capabilities. Our facilities and staff stand ready to meet your research and development testing needs.

Cordially,

Olga Gonzalez-Sanabria
Director of Engineering and Technical Services

Table of Contents

NASA Glenn's Premier Research Test Facilities

Engine Components

NASA GRC offers a large variety of engine component facilities supporting turbine engine research and development. These facilities are essential to support NASA, industry, and academia in advancing future development of aerospace engine technologies. Supporting NASA's efforts for quieter and more fuel-efficient turbine engine technology development, as well as research for access to space propulsion systems, are just some of the varied test capabilities supported at these facilities. Detailed facility test capabilities information is available on page 39.

The Aero-Acoustic Propulsion Lab (AAPL) provides unique nozzle and fan test rigs to evaluate engine noise reduction concepts.

The Engine Research Building (ERB) is the largest and most adaptable test facility complex at GRC, housing more than 60 test rigs. Most aspects of engine development can be studied here with numerous facilities specializing in turbomachinery, tribology, flow physics, combustion, aerochemistry, mechanical components, and heat transfer.

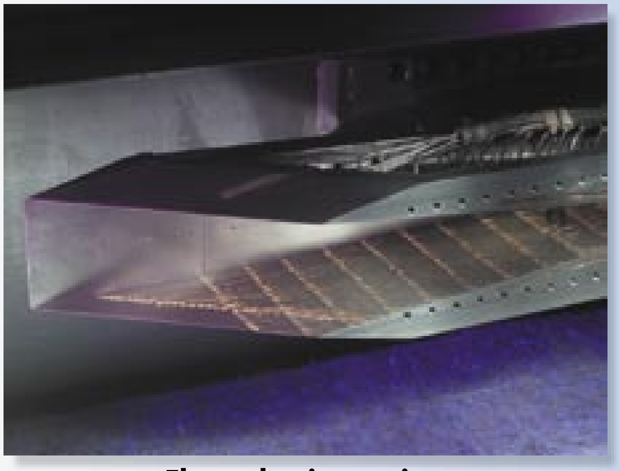
The Engine Components Research Laboratory (ECRL) Cell 1B is a unique combustor facility able to evaluate augmentor and afterburner concepts. ECRL can support a variety of test configurations and in recent years has evaluated hybrid propulsion systems for aerospace applications.

The Advanced Subsonic Combustor Rig (ASCR) is NASA GRC's unique high-pressure combustor facility, able to simulate combustor inlet conditions up to 900 psig.

Turbomachinery testing

Combustor testing

Nozzle and fan acoustics testing



Flow physics testing

Aero-Acoustic Propulsion Laboratory (AAPL)

The AAPL is essential in supporting NASA's engine noise-reduction research for nozzle and fan components.

The AAPL is an acoustically treated geodesic dome that houses three acoustic tests rigs supporting engine noise-reduction research at GRC. AAPL's two nozzle rigs and one fan rig have been actively used to support these research efforts.

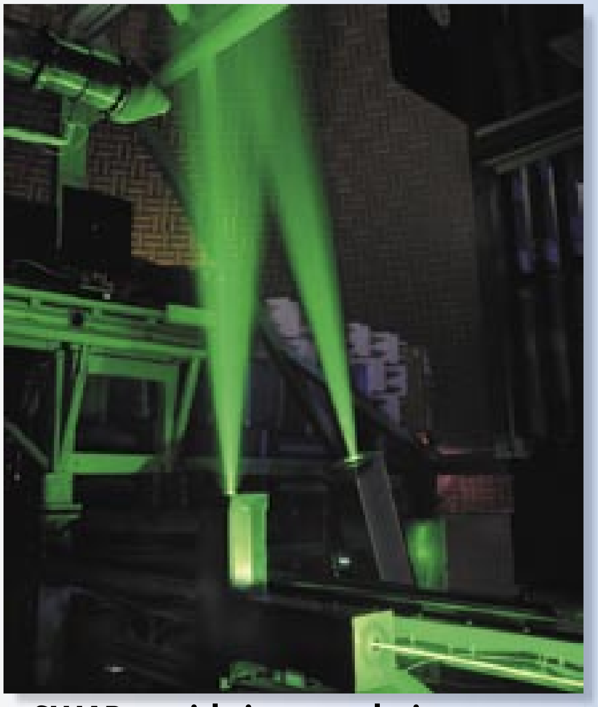
The Nozzle Acoustic Test Rig (NATR) is a free-jet acoustic tunnel used to evaluate acoustic performance of nozzle concepts at simulated flight conditions up to Mach 0.35. Two microphone arrays are used to acquire sideline and flyby acoustic data. These microphone arrays are located about 50 feet radial from the nozzle exhaust, providing a unique far-field acoustic environment to evaluate nozzle concepts. A High Flow Jet Exit Rig (HFJER) is used to mount nozzle concepts in the NATR and can simulate engine cycle conditions in single- or dual-flow nozzle configurations. The NATR has contributed significantly to research in chevron nozzle development, which has demonstrated substantial noise reduction with no impact on thrust performance.

The Small Hot Jet Acoustic Rig (SHJAR) is a small nozzle acoustic test rig for fundamental nozzle acoustic research that allows researchers to evaluate potential noise-reduction nozzle concepts very economically. SHJAR is tested in a single-flow configuration with no tunnel flight simulation. Promising nozzle concepts can be scaled up and acoustically evaluated using NATR.

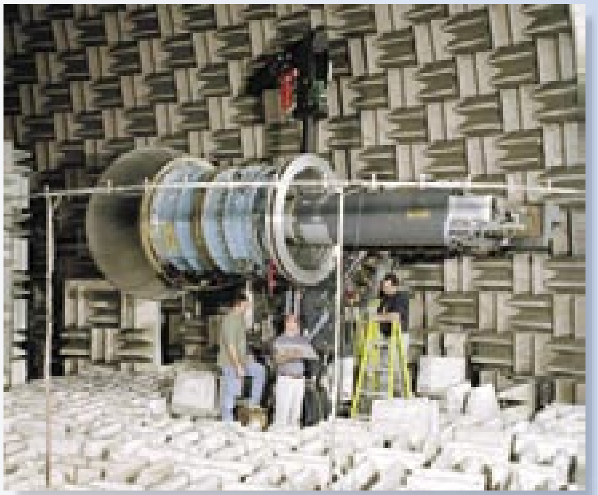
NATR and SHJAR can support several advanced diagnostic testing capabilities to provide researchers a means of better understanding nozzle exhaust conditions. Measurements of pressures and temperatures can be acquired using a traversing plume survey system. Particle image velocimetry, phased-array acoustic source identification, and Schlieren and shadowgraphy help researchers gain invaluable insight into the physics of jet noise generation and methods for its reduction.

The Advanced Noise Control Fan (ANCF) rig is used to support fundamental noise-reduction research on fan components and allows researchers the flexibility to evaluate a variety of rotor and stator configurations. It was developed to test noise-reduction concepts, test noise measurement concepts, and provide a flexible and realistic aeroacoustic source for computational aeroacoustic code verification. The unique rotating rake measurement system can obtain both radial and circumferential mode measurement for the inlet and exhaust ducts. ANCF uses a 4-ft-diameter fan and can support testing up to 2600 rpm. A compact farfield acoustic array is used to obtain inlet and exhaust acoustic measurements.

NATR nozzle acoustic test



SHJAR particle image velocimetry test



ANCF fan acoustic test

Engine Research Building (ERB)

The ERB supports research on all aspects of engine development, providing superior testing of turbomachinery, aerodynamics, flow physics, aeropropulsion heat transfer, mechanical components, and combustor facilities.

Combustor Facilities:

GRC provides modern combustor facilities supporting low-emission combustor research and development testing in partnership with industry. Fundamental and applied research is aimed at advancing the technology of the combustion processes of aeronautical gas turbine engines and advanced space transportation concepts. Research is focused on providing improved understanding of chemical kinetics of reacting flows, heat transfer phenomena, advanced high-temperature materials, low NOx combustion, and code development and validation.

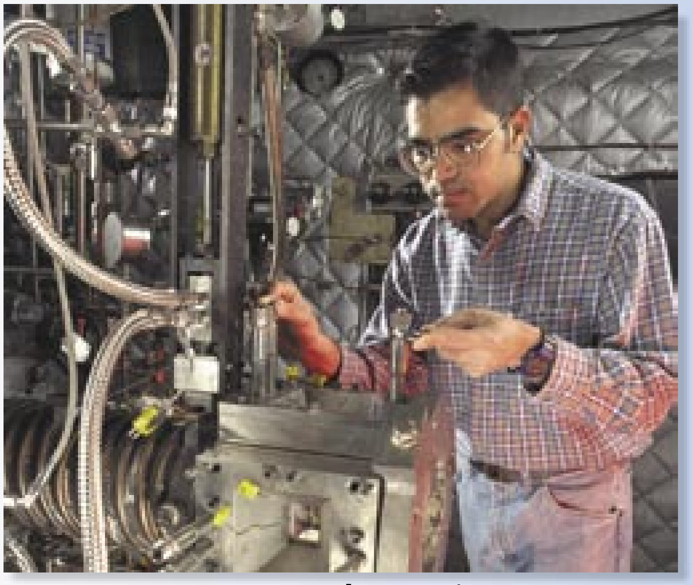
GRC's ERB complex offers a wide variety of combustor facilities and currently has 15 facilities supporting these research efforts. ERB combustor facilities vary in capabilities simulating pressures up to 450 psig, flow rates up to 30 lbm/sec, and inlet combustor temperatures up to 1350 °F.

Heat Transfer Facilities:

Testing capability for experiments to advance fundamental understanding of the heat transfer process and to contribute to the predictive capability for heat transfer in aeronautical and space propulsion systems is provided in the heat transfer facilities. Research in these facilities centers on gas turbine-related heat transfer with special emphasis placed on gas path aero and heat transfer. Six aeropropulsion heat transfer technology facilities are located in the ERB.

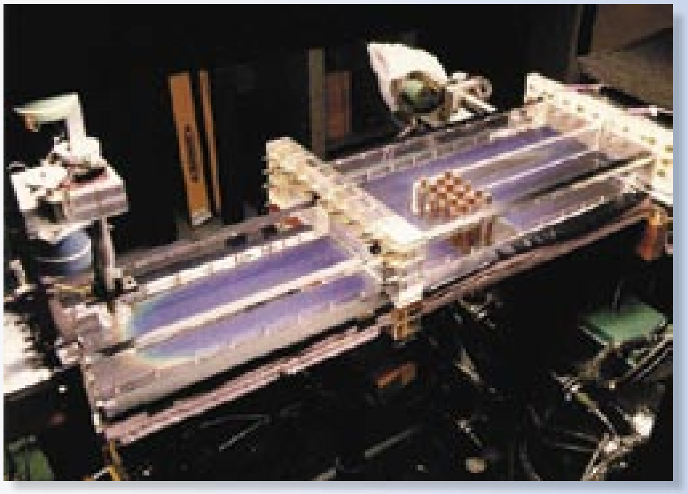
Mechanical Components Facilities:

Research and development in mechanical components and systems technologies to improve the performance, reliability, and integrity of aerospace drive systems, high-temperature seals, and space mechanisms is performed in the facilities. Several gear, bearing, and transmission facilities are located in ERB to support research on fatigue life testing, lubrication, materials, noise, vibration, and thermal effects on these components.



CE–5B combustor rig

CE–9B–B high-temperature flametube injector test stand



A liquid crystal-coated model being tested in SW–6

Engine Research Building

Turbomachinery Facilities:

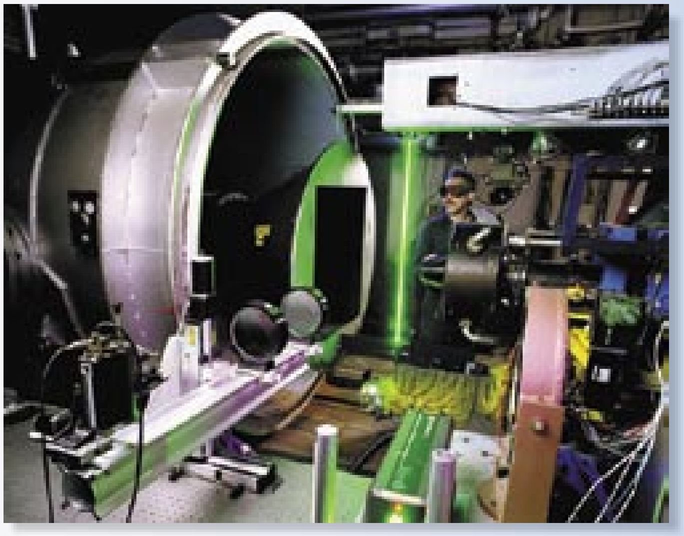
Fundamental and applied research to advance compressor and turbine component technology for aeronautical gas turbine engines is conducted in the facilities. Both axial- and radial-type machinery are studied. Research is focused on improved understanding of steady and unsteady aerodynamics, flow physics, and modeling and advanced numerical flow code development and validation. Research experiments utilize advanced instrumentation systems such as hot-wire anemometry and laser diagnostics where detailed flow data is obtained on a nonintrusive basis. GRC currently has 11 facilities supporting this research effort.

GRC's ERB complex offers a wide variety of turbomachinery facilities and currently has eight facilities supporting these research efforts. ERB turbomachinery facilities can support axial compressor and fan component testing ranging in sizes up to 22 in. in diameter. A maximum of 15 000 hp at rotational speeds up to 21 000 rpm can be supported. Also, a centrifugal compressor facility can support testing up to 60 000 rpm for compressor ranging from 8 to 20 in. Supply airflow and exhaust conditions can be varied at each facility depending on the test requirements.

Flow Physics Facilities:

Research advancing the understanding of subsonic-to-supersonic flow physics phenomena fundamental to ducted wall-bound flows is conducted in the flow physics facilities. Research involves the development, assessment, and application of computational fluid dynamics tools for ducted flows and for the acquisition and analysis of experimental measurements of flows in inlets, ducts, and nozzles. Typically, testing is performed to define basic flow properties, to predict and validate component performance, and to investigate specific phenomena including shock systems, boundary layers, bleeds, diffusion, separated flows, heat transfer, cooling, spillage, acoustics, and stability. GRC currently has eight facilities supporting this research effort.

Compressor test in W–7



CE–22 nozzle test

Pratt & Whitney F–119 nozzle test in flow physics facility

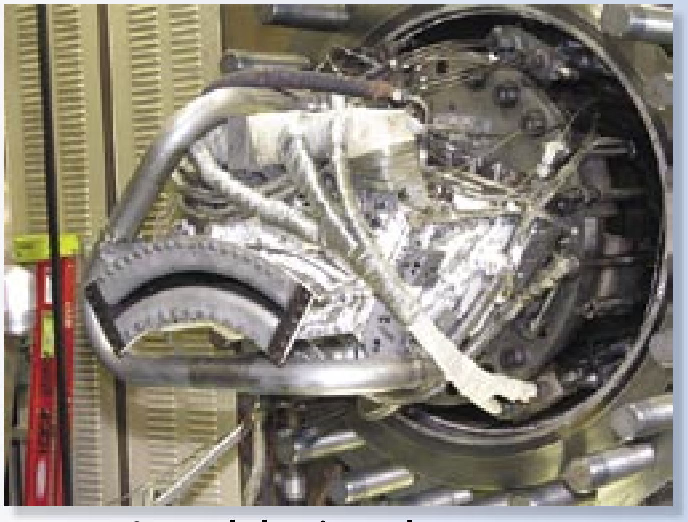
Advanced Subsonic Combustion Rig (ASCR)

The ASCR is the highest pressure combustor facility in the United States, able to simulate combustor test conditions up to 900 psig.

The ASCR is NASA GRC's unique high-pressure and high-temperature combustor facility supporting the emissions reduction projects. The facility has the capability of simulating combustor inlet test conditions up to a pressure of 900 psig and temperature of 1200 °F (nonvitiated). To accomplish the higher pressure test capability, ASCR has a dedicated high-pressure compressor, which pressurizes the GRC centrally supplied 450 psig combustion air to 900 psig. The maximum facility airflow is 50 lb/sec and maximum combustor exhaust gas temperature is 3400 °F.

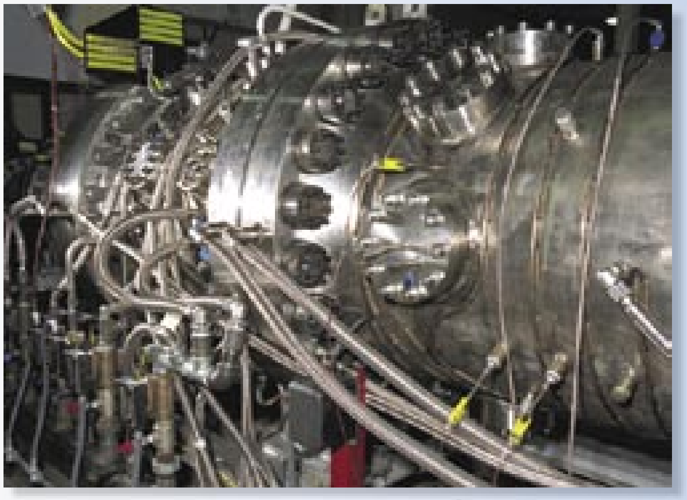
NASA and its industry partners are working to develop low NOx combustors, which will operate at pressure ratios up to 55:1 as part of turbine engine technology development programs. A facility like ASCR is essential to support combustor development at these high pressures and provides NASA and U.S. engine manufacturers with the ability to quantify the effects of higher pressure on combustor emissions, durability, and operability.

The first-ever laser diagnostics measurements in a practical gas turbine combustor at high pressures was conducted in the ASCR. Nonintrusive laser-based diagnostic measurements are performed in windowed test sections. ASCR acquired two-dimensional fluorescence measurements within a gas turbine combustor sector at 42 atmospheres and one-dimensional Raman scattering measurements within a gas turbine combustor sector at 48 atmospheres. These measurements can be used to visualize the fuel injection, fuel-air mixing, and combustion processes within high-temperature, high-pressure gas turbine combustor sectors and simulators.



General Electric combustor test

ASCR sector



ASCR sector stand

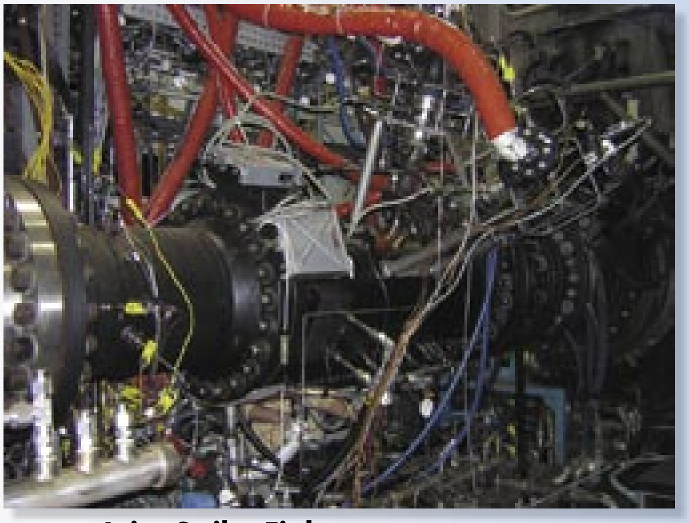
Engine Components Research Laboratory (ECRL) Cell 1B

The ECRL Cell 1B is a versatile combustor facility supporting development for a wide range of engine propulsion concepts.

ECRL Cell 1B is a full-scale combustor rig used to test and evaluate advanced engine combustor and afterburner concepts in a realistic engine environment. Inlet air pressure can be supplied at 40, 125, or 150 psig with flow rates up to 100 lbm/sec. The air can be heated to 625 °F via a nonvitiating preheater. Aviation fuels used in ECRL Cell 1B are typically JP–4, JP–5, or Jet-A; though specialized fuel can be utilized.

The test section is typically 4 to 5 feet long, and the flow can be split into a core and fan stream. The ratio of core airflow is usually 1.2, but can be varied by changing the orifice plates. Core air can further be heated by a J–58 combustor; the maximum J–58 outlet temperature is 2000 °F. Additional fuel can be added in the test section area, thereby increasing the exit temperature beyond 2000 °F. ECRL Cell 1B can use its own atmospheric exhaust, or it can use the GRC altitude exhaust, which has a maximum exhaust vacuum of 2 psia (50 000 ft altitude).

This cell has supported testing for pulse detonation engines and Rocket-Based Combined Cycle (RBCC) combustor instability and materials durability research. Gaseous hydrogen (1500 psig at 1.0 lb/sec) and oxygen (1500 psig at 4.0 lb/sec) testing capability were added to support RBCC aerospace propulsion research. Gas analysis, facility controls, and data system enhancements have been incorporated for versatile support of varied test requirements. The cell is very useful to the research community providing the flexibility to test a wide variety of hardware configurations.



Joint Strike Fighter augmentor test

Control room

Rocket-Based Combined-Cycle test

Engine

GRC has the unique ability to conduct a full spectrum of jet engine testing including product development, component testing, and full-scale testing. The Propulsion Systems Laboratory (PSL) is NASA's only ground-based test facility that provides true flight simulation for experimental research on air-breathing propulsion systems. This continuous flow altitude simulation facility is equipped to conduct full-scale and component testing for base research, advanced aircraft, space transportation, general aviation propulsion, and hypersonic propulsion. The Engine Component Research Laboratory (ECRL) Cell 2B supports small turbine engine research. Detailed facility test capabilities information is available on page 40.

Williams International FJX engine test in PSL

T–700 active stall control engine demonstration test in ECRL

General Electric (GE) F–110 engine test in PSL

Engine Components Research Laboratory Cell 2B

The ECRL Cell 2B is NASA's small turbine engine test facility conducting research in partnership with the Army Research Laboratories.

The ECRL Cell 2B has been in use since 1979 to conduct turbine engine research on T–700, T–800, and T–55 engines of mutual interest to the U.S. Army and NASA GRC. Past test programs have investigated ceramic and brush seal technology, hydrogen burner thermal inlet distortions, active vibration control of high-speed shafting, alternate fuels, compressor stall and active stall control, and digital fuel control technology.

The test cell can be operated as a ground-level turboshaft facility or as an altitude facility for core engine tests. As a ground-level test facility, the cell can operate turboshaft engines up to 2500 shp. The cell is equipped with a water brake system. Engine inlet air is supplied from the test cell through an inlet flow measurement venturi and a 78-in.-diameter plenum. The facility has an engine inlet particle separator (IPS) scavenge and measurement system, which utilizes a blower and control valves for setting IPS back pressure conditions. Engine exhaust is scavenged by a 48 000 scfm blower or through the GRC centralized altitude exhaust system.

The facility also has the capability of testing turbofan or turbojet engines under simulated altitude conditions in a 6-ft-long by 6-ft-wide by 7-ft-high chamber. This chamber is connected to the GRC altitude exhaust system and can achieve pressures down to 2.0 psia simulating altitudes of 46 000 ft.

The facility can accurately measure and record approximately 600 channels of instrumentation including pressures, vibrations, temperatures, and flow rates. These can then be analyzed in our data system to determine engine performance and operability.

T–700 engine test

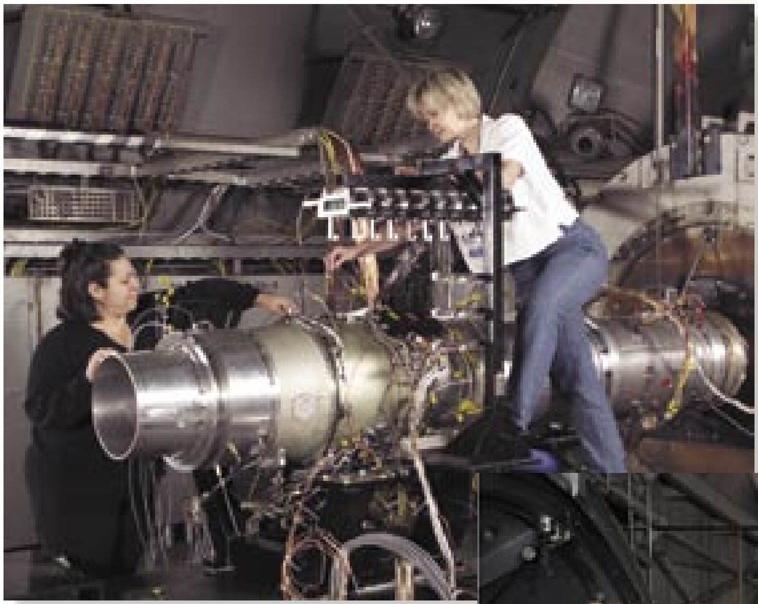
T–55 engine test

Propulsion Systems Laboratory (PSL)

The PSL is NASA's only ground-based test facility that provides true flight simulation for experimental research on air-breathing propulsion systems.

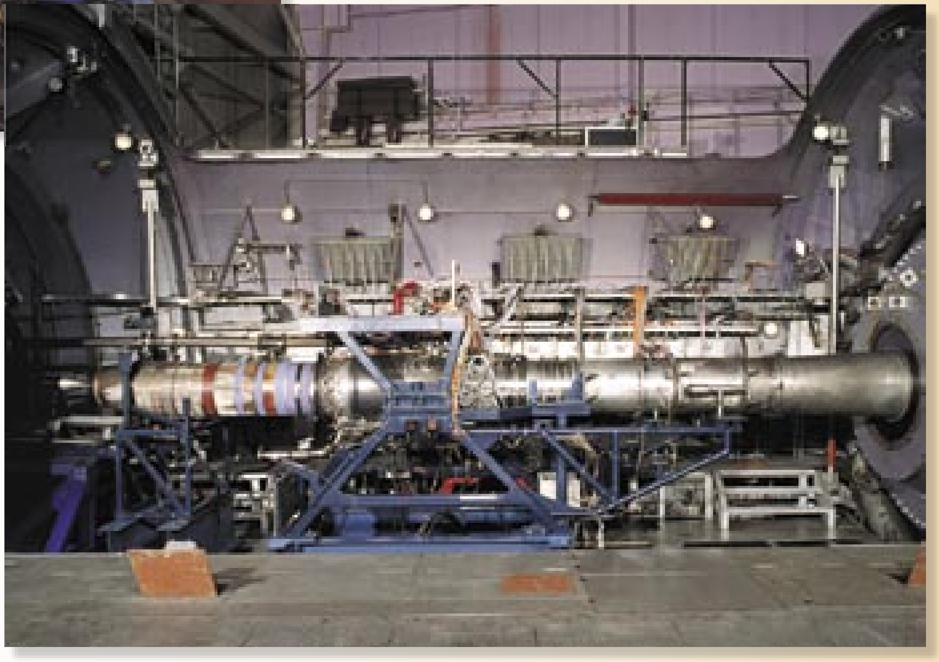
The PSL is a national resource to ensure the technical leadership and economic strength in the world of the U.S. industry, which designs, develops, and manufactures engines and propulsion systems for aeronautical and space applications is maintained. PSL supports the development of new technology critical to our national defense and security. The research performed provides detailed information on the performance and operability of engines and propulsion systems at extreme conditions over the entire flight envelope, which can only be obtained through altitude-simulated, ground-based testing. This facility is significant because it is NASA's only ground-based, full-scale engine test facility that can provide true flight simulation. There are two large engine test chambers for conducting experimental research on air-breathing propulsion systems.

Using onsite compressors, exhausters, and heating and cooling systems, PSL can accurately create temperature and pressure inlet conditions that propulsion systems experience in high-speed, high-altitude flight. Of the two test chambers, PSL–3 is used primarily for military class turbine engines and explores all facets of advanced aircraft research. PSL–4 incorporates a high temperature and pressure inlet plenum and can meet the needs of high speed and altitude propulsion system research for both aviation and access to space applications.



Williams International F–J33 turbofan engine test

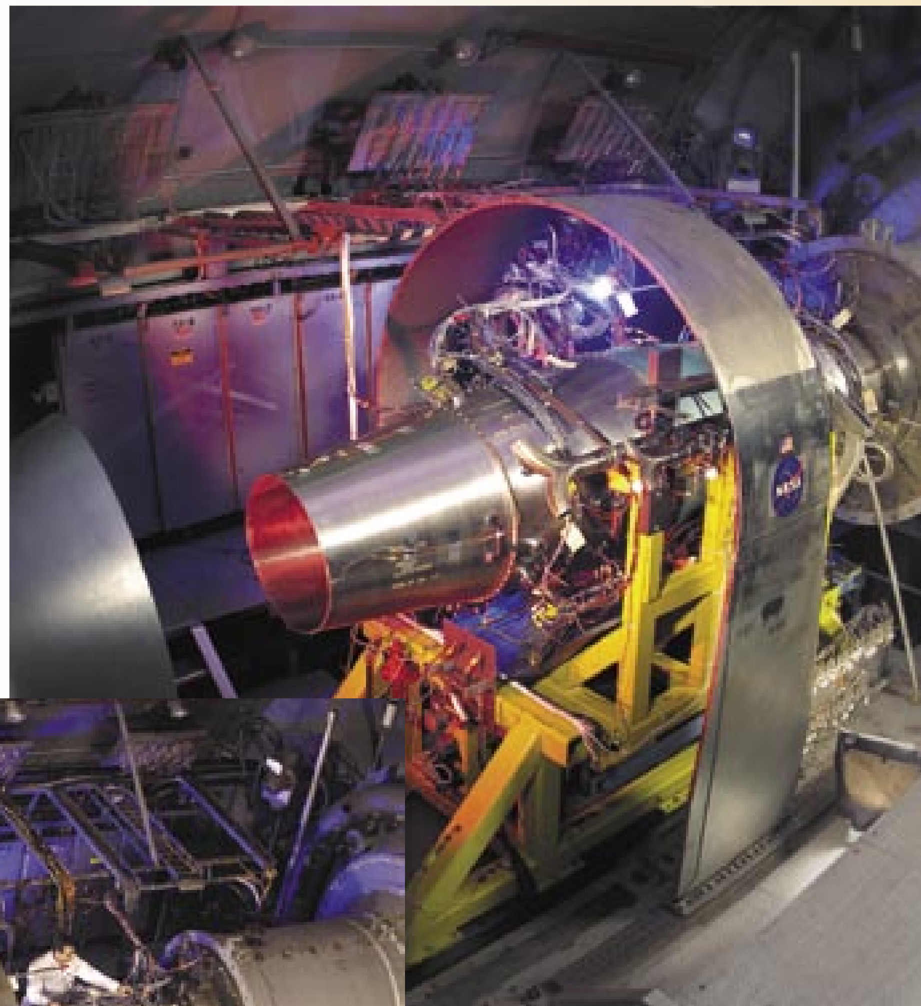
F–405 engine test



Propulsion Systems Laboratory

PSL uses a variety of additional specialized systems to investigate these future propulsion systems including liquid and gaseous fuels, multi-axis thrust measurements, and exhaust vectoring and collection. A user friendly, configurable data acquisition system is capable of displaying and recording over 1000 static measurement channels, and an additional 160 channels have a combined throughput of 40 million samples per second for time-varying measurements. NASA has highly experienced, versatile personnel with the ability to react to new program goals and changes that arise unexpectedly from ongoing experimental research. The scientists and engineers that employ the capabilities at PSL are experts in engine performance, maintenance, and operations, aeroelastic measurements, flight transient operations, and transient temperature and pressure distortion simulations.

PSL has supported such aircraft programs as the SR–71, F–16, F–15 STOL, and the B52 and has conducted basic research on advanced aircraft, space transportation, general aviation propulsion, and hypersonic propulsion.



Pratt & Whitney engine test

Wind Tunnels

NASA Glenn operates and maintains several wind tunnels in accordance with its commitment to researching innovative propulsion technologies and flight safety. Spanning the operating speed range of 0 to Mach 7, the wind tunnels offer unique aerodynamic and propulsion test capabilities to support the diverse needs of our customers.

The wind tunnels have developed the capabilities, systems, and expertise to execute tests in areas such as basic flow physics, code validation, proof-of-concept, small-scale component research, icing protection systems development and certification, inlet/airframe integration, large- and full-scale component research and development, system integration, acoustics, aerodynamic force and moment, short takeoff and vertical landing, space launch vehicles, propulsion systems (live burning), and nontraditional wind tunnel activities. These tests have been efficiently and effectively conducted for NASA, other Government agencies, academia and commercial corporations in the aeronautics and space communities. Detailed facility test capabilities information is available on *page 41.*

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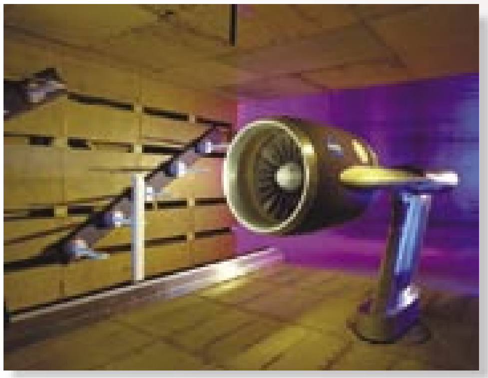
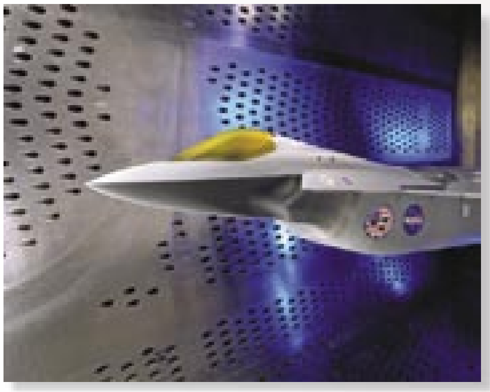
Ice protection system development and certification

Large- and full-scale component/system testing



Aerodynamic and acoustic testing

Basic research and proof-of-concept and code validation



Inlet/airframe integration testing

Hypersonic testing

Icing Research Tunnel (IRT)

The IRT is one of the world's largest refrigerated wind tunnels dedicated to the study of aircraft icing.

The IRT is Glenn's oldest and busiest facility. Built at the end of World War II to solve aircraft icing problems, the IRT has been in continuous operation since 1944. In this facility, natural icing conditions are duplicated to test and study the effects of in-flight icing on actual full-size aircraft components and models of aircraft, including helicopters. The IRT has played a substantial role in developing, testing, and certifying methods to prevent ice buildup and develop next-generation ice protection systems for military and commercial aircraft.

A variety of tests are performed in the IRT including

- Ice protection system development and certification
- Fundamental studies of icing physics
- Icing prediction validation
- Investigation of de-icing and anti-icing fluids for use on ground and on aircraft
- Icing Code Validation

The IRT can simulate actual flying conditions by providing airspeeds ranging from 50 to 350 mph and air temperatures as low as –30 °C, controllable to within 1°F. A uniform test section icing cloud approximately 5 ft high by 6 ft wide can be created. Detailed analysis and electronic storage of ice shape data in addition to a wide variety of data collection and observation methods are used. Permanent casting and physical tracing of ice formation are also created for extended study.

With over 50 years of knowledge and experience in the icing arena, Glenn has collaborated with the Federal Aviation Administration and industry to improve current capabilities in ice shape simulation and identify shape features most critical for evaluation of aircraft performance. This research is directed at understanding the physical process underlying the ice accretion processing including phenomena associated with super-cooled large-droplet ice accretion.

Boeing V–22 radome icing test

Sikorsky Black Hawk rotor blade icing test

Twin Otter wing section comparison of flight conditions

9- by 15-Foot Low-Speed Wind Tunnel (9×15 LSWT)

The 9×15 LSWT is the most utilized low-speed propulsion acoustic facility in the world and is the only national facility that can simulate takeoff, approach, and landing in a continuous subsonic flow wind-tunnel environment.

The 9×15 LSWT is used to test large-scale hardware in a continuous flow, calibrated subsonic airstream. Providing airspeeds from 0 to 175 mph, the test section can be configured to support both aerodynamic and acoustic testing of a variety of models.

With the ever-increasing demand for reducing aircraft noise, the 9×15 LSWT has the unique and nationally recognized ability to evaluate the aerodynamic performance and acoustic characteristics of fans, nozzles, inlets, and propellers. The test section is acoustically treated and equipped with microphones linked to a dynamic data system to allow acoustic research at frequencies as low as 250 Hz. A series of drive rig systems are available to power engine fan models for performance and acoustic testing. A unique "rotor-alone nacelle" test capability allows isolation of fan-alone noise by elimination of the outlet guide vanes. The 9×15 LSWT also has the ability to investigate hot gas reingestion of advanced short takeoff and vertical landing (STOVL) concepts.

Support systems include steady-state and dynamic data acquisition systems with real-time data displays, infrared imaging, sheet lasers, Laser Doppler Velocimetry, pressure- and temperature-sensitive paint, heated high-pressure air, exhaust, and hydraulics.

The 9×15 LSWT has supported research on a variety of commercial aircraft propulsion systems, the High-Speed Research program, the Joint Strike Fighter program, and other military STOVL aircraft applications.

STOVL hot gas ingestion model

Rotor-alone nacelle system installation

Lockheed Martin inlet/airframe integration model

8- by 6-Foot Supersonic Wind Tunnel (8×6 SWT)

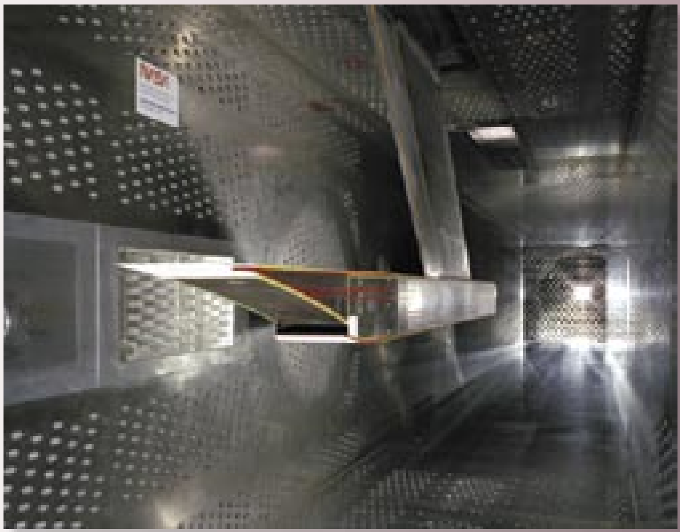
The 8×6 SWT is NASA's only transonic wind tunnel with propulsion test capabilities, providing test section speeds of Mach 0.25 to 2.0.

The 8×6 SWT provides researchers the opportunity to explore the subsonic, transonic, and supersonic speed range in a calibrated test section. The 8×6 SWT supports research of advanced aircraft concepts and components, engines for high-speed aircraft, and launch vehicle concepts.

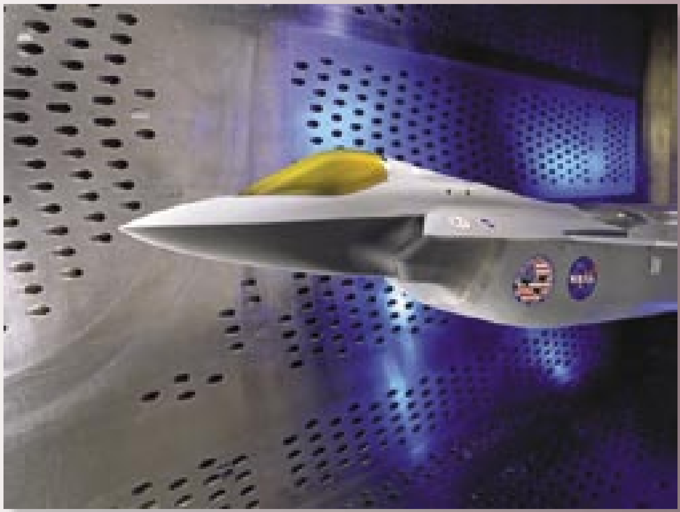
The 8×6 SWT can operate in either an aerodynamic cycle (for testing the aerodynamic performance of components, such as inlets, nozzles, and propellers or integrated systems) or in a propulsion cycle (for testing live engines or propulsion systems). The 8×6 SWT is also equipped to accommodate force and moment scale models.

Support systems include steady-state and dynamic data acquisition systems with real-time displays, heated pressure air, exhaust, pressure- and temperature-sensitive paint, hydraulics, Schlieren, supersonic and transonic strut mounts, and gaseous hydrogen. An assortment of test hardware is available to support our customer's test needs.

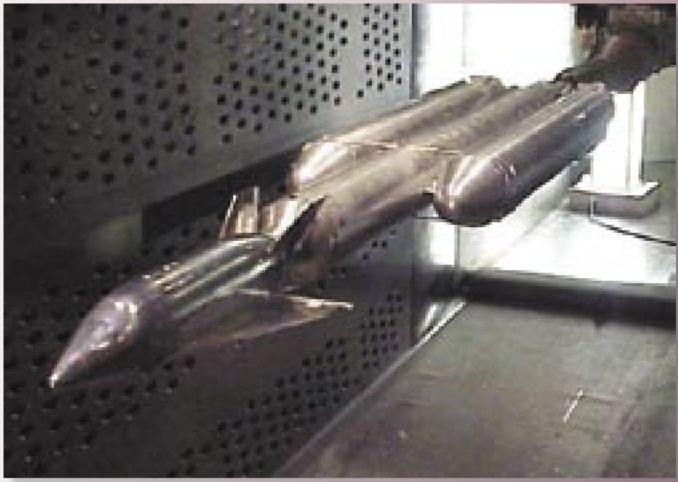
With a history of testing that includes the space shuttle, the National Aerospace Plane, and the Joint Strike Fighter, and an active role in support of NASA, DOD, other Government agencies and commercial corporation programs, the 8×6 SWT is prepared to provide technically proficient and cost-effective wind tunnel testing to meet and exceed customer requirements.



Live burning test of National Aerospace Plane nozzle



Joint Strike Fighter model



Space transportation system

10- by 10-Foot Supersonic Wind Tunnel (10×10 SWT)

The 10×10 SWT is the largest and fastest wind tunnel at NASA GRC, providing test section speeds of Mach 2.0 to 3.5.

The 10×10 SWT, also called the *Abe Silverstein Supersonic Wind Tunnel,* is the largest and fastest wind tunnel at Glenn, specifically designed to test supersonic aerodynamic and propulsion components such as inlets and nozzles, integrated propulsion systems, full-scale jet and rocket engines, and launch vehicle concepts.

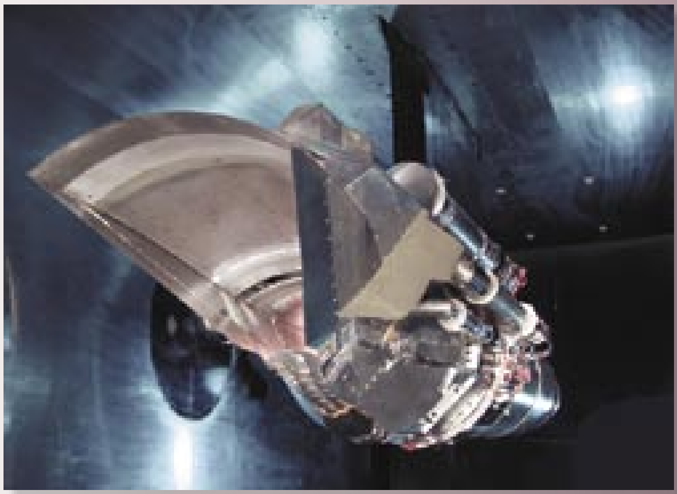
The 10×10 SWT can operate as either a closed-loop (aerodynamic cycle) or open-loop (propulsion cycle) system and can reach test section speeds ranging from Mach 2.0 to 3.5. Recent upgrades allow the facility to operate subsonically from 0 to Mach 0.36. The test section, 10 ft high by 10 ft wide by 40 ft long, can accommodate large-scale models and some full-scale engines and aircraft components. Recent programs have supported a wide variety of test types, from aerodynamic force and moment tests to live burning propulsion system tests.

The 10×10 SWT is supported by steady-state and dynamic data acquisition systems with real-time displays, high-pressure air, exhaust, hydraulics, liquid jet fuels, and gaseous hydrogen and oxygen. An assortment of test hardware is available to support our customer's test needs. Advanced optical instrumentation such as standard and focused Schlieren systems, sheet lasers, and pressure- and temperature-sensitive paint are also employed.

The 10×10 SWT has contributed to fundamental aeropropulsion technology research and vehicle-focused research programs such as the space shuttle, the High-Speed Civil Transport, and the National Aerospace Plane. It continues to contribute in areas such as sonic boom mitigation, propulsion system and component evaluation, engine and airframe integration, and launch vehicle systems.

NASA Glenn/NASA Langley load-comparison tests

Rocket-Based Combined-Cycle (RBCC) test



Parametric Inlet test

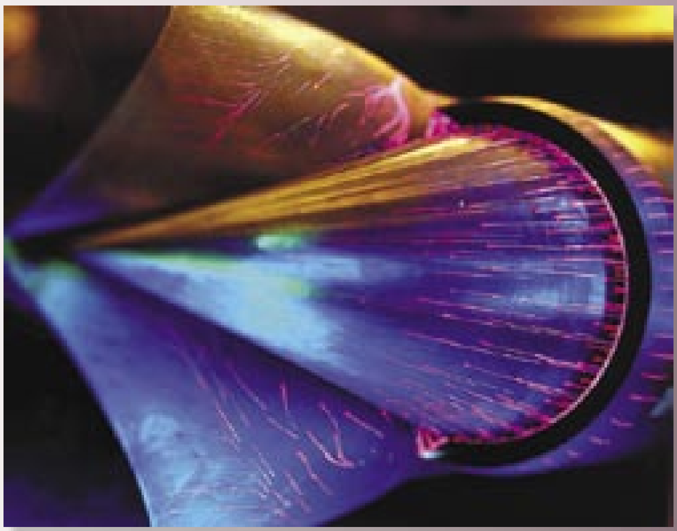
1- by 1-Foot Supersonic Wind Tunnel (1×1 SWT)

The 1×1 SWT is an excellent low-cost testing tool for small-scale research, simulating speeds ranging from Mach 1.3 to 6.0.

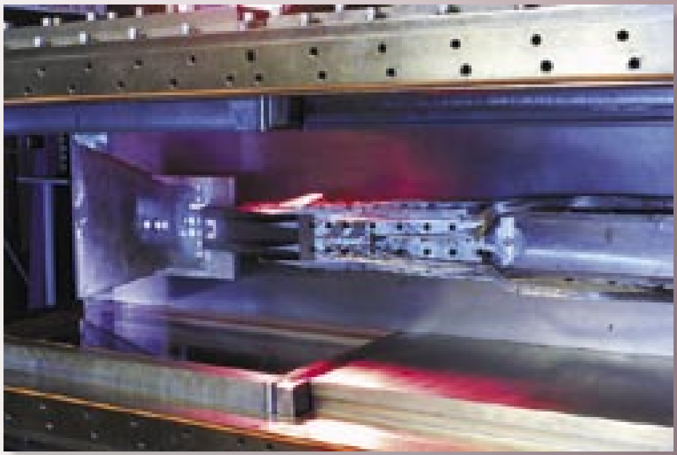
The 1×1 SWT specializes in conducting fundamental research in supersonic and hypersonic fluid mechanics, supersonic-vehicle-focused research, and detailed benchmark-quality experiments for computational fluid dynamic code validation. With the facilities unique capabilities, expert staff, and efficiency the 1×1 SWT offers the supersonic research community an excellent low-cost testing tool for small-scale research.

The 1×1 SWT can provide continuous tunnel operation at 10 discrete airspeeds between Mach 1.3 and 6.0. One of the biggest advantages of testing in the 1×1 SWT is that researchers can conduct early proof-of-concept tests; if an outcome is promising, they can scale up their models for testing in larger tunnels, thus avoiding the immediate cost of full-scale modeling and testing. Another advantage is the up-close viewing of conditions in the tunnel. Test articles can be mounted on any of the four walls of the test section, which can be configured to provide a variety of instrumented plates and optical-quality glass panels.

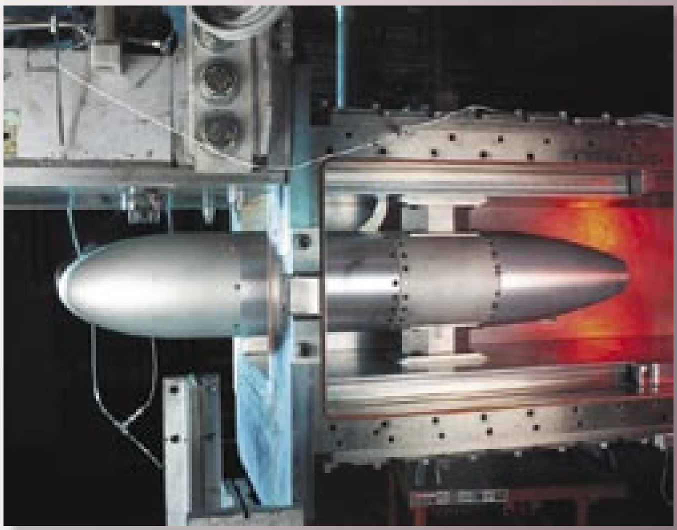
Specialized support systems are available such as exhaust, high-pressure air, model hydraulics, and probe actuation systems. Flow can be visualized with the use of Schlieren, a sheet-laser system, or blue Zyglo and black lights. Quantitative flow-field measurements can be made with a two-component laser Doppler velocimeter.



Oil flow visualization on the GTX inlet test rig



Integrated System Test of Air-Breathing Rocket (ISTAR) inlet testing

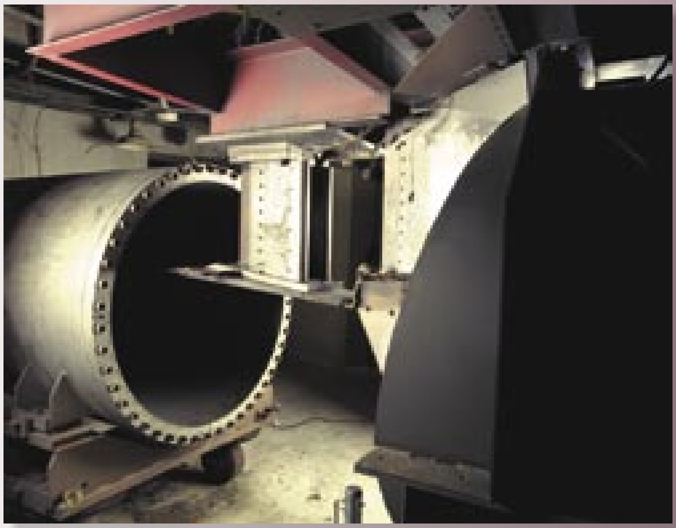


Pulsed ejector wave propagation test rig

Hypersonic Tunnel Facility (HTF)

The HTF tests large-scale hypersonic air-breathing propulsion systems.

HTF testing in direct-connect mode



RBCC hypersonic engine test

Originally designed to test nuclear thermal rocket nozzles, the HTF located at Glenn's Plum Brook Station is a hypersonic (Mach 5, 6, and 7) blowdown, nonvitiated (clean air) wind tunnel capable of testing large-scale propulsion systems at true enthalpy flight conditions. Located upon 6400 acres, the test site has a generous exclusion zone that allows for high-energy, high-risk testing.

The HTF contains a large experimental infrastructure that can be readily configured to meet a variety of ground test applications including megawatt-level thermal heating, cooling, and electrical systems and large-capacity gas storage. Enhancements to provide direct-connect testing of large-scale combustors at hypersonic flow conditions are underway. Test articles can experience multiple gas flow inputs up to 220 lb/sec at temperatures and pressures up to 3600 R and 1200 psig and altitude conditions up to 120 000 ft.

HTF is equipped to test large-scale propulsion systems and flight-rated structures at hypersonic conditions. The primary performance differentiator between HTF and other hypersonic facilities is that it uses nonvitiated (clean air) flow whereas traditional hypersonic facilities utilize a combustion process to generate high enthalpy conditions required to simulate hypersonic flows. HTF generates these conditions by flowing clean nitrogen gas through a 3 MW graphite core storage heater. This heated nitrogen is then mixed with ambient temperature oxygen and ambient temperature nitrogen to yield a flow of synthetic (true composition) clean air at the requisite stagnation temperature. A single-stage steam ejector is used to exhaust the facility flow and provide altitude simulation. Propulsion testing in a facility with nonvitiated (clean air) flow most closely represents the actual flight conditions and minimizes potential errors between ground test results and true flight performance.

The facility is also unique due to its large scale. The test section can accommodate test articles that are up to 14 feet in length. The facility's size along with its long run duration allow for full systems testing of large-scale flight-rated structures and propulsion systems. This ability to test near full-scale systems minimizes the potential scaling errors associated with ground testing at hypersonic conditions. In addition, the HTF contains the Agency's only large-scale nonreacting heater core that could be used in the development of future nuclear thermal propulsion systems. This 3 MW heater is fully operational and is staffed by a crew that is fully trained in its use and operation. The facility has an additional 10 MW of power available at the site to meet any other high-energy testing requirements.

Flight Research

The Flight Research Building is home to many unique and innovative aircraft, including the two Learjets, the S3–B, the T34C, and the Twin Otter icing research aircraft.

NASA GRC uses a high-performance Learjet Model 25 aircraft as an economic testbed for a wide variety of remote-sensing photographic applications and other diverse technology. Tests on the Learjet include assessing chevron nozzles to reduce jet engine noise, laminar flow nacelle contours with anti-insect coatings, fiber-optic temperature-sensing devices, space communications, acoustical effects, microwave-scanning-beam landing systems for the space shuttle, and microgravity research. One Learjet is also known worldwide for its high-altitude calibration of solar cells, which must be performed at the top of the Earth's troposphere where light absorption due to the atmosphere is very predictable.

Learjet Model 25 aircraft

NASA Glenn's extensively modified DeHaviland DHC–6 Twin Otter is used primarily during the winter months as a natural icing test platform to study icing conditions. This aircraft is used to fly into ice conditions to characterize the environment for ground-based simulation, to document ice shapes on the aircraft, and to measure performance changes due to icing. The Twin Otter uses a combination of pneumatic de-icing boots and electrothermal anti-icing and de-icing methods, which allows NASA to selectively de-ice aircraft surfaces to evaluate the effects of ice on performance, stability, and control. Also used for low-altitude Earth observation and atmospheric sampling.

DeHaviland DHC–6 Twin Otter aircraft

The S–3B Viking aircraft was built as a carrier-based antisubmarine platform. The S–3B is commonly referred to as the "Swiss Army knife of naval aviation" due to its long range at low altitudes, long loiter times, and abundant rack and equipment space. The S–3B is used for fundamental studies of icing and cloud physics, icing prediction validation, ice detection and protection system development and certification, and development of safety procedures for pilots. The S–3B will allow researchers to test a wide variety of flight regimes that are currently inaccessible to the Twin Otter. It is also available for multiple airborne projects.

S–3B Viking aircraft

GRC recently acquired a Navy T–34 single-engine turboprop aircraft suitable as a cost-effective low-speed research platform for photo chase, Earth observation, atmospheric sampling, etc. *Detailed aircraft information is available on page 42.*

Microgravity

For over 30 years, GRC has played a major role in planning, directing, and implementing space experiments in technology and microgravity science. The focus of microgravity research is to conduct scientific and technology studies to enhance the understanding of the role of gravity on physical phenomena including materials science, power, propulsion, combustion, fluid physics, plasma physics, etc., enabling new technology for future space missions and expanding our scientific knowledge for terrestrial applications. Detailed facility test capabilities information is available on page 43.

2.2-Second Drop Tower

Microgravity, a condition of relative near-weightlessness, can only be achieved on Earth by putting an object in a state of free fall. One of the most significant and substantial areas of microgravity includes the design, buildup, testing, and integration of hardware for experiment packages to be launched aboard the space shuttle. The success of many of NASA's space flight experiments is due in part to the ability to test space experiment concepts and hardware here on Earth in the Zero-Gravity Research Facility, the 2.2-Second Drop Tower, and C–9 aircraft.

Flight research test in the C–9 aircraft

One of NASA's most heavily used ground-based microgravity facilities is the 2.2-Second Drop Tower. It provides 2.2 seconds of low-gravity test time using vertical free fall for experiment packages up to 159 kg. The tower is used for study of combustion and fluid phenomena in low gravity. This research has applications in spacecraft fire safety, flammability and fire detection, pollution detection and mitigation, and biotechnology. The facility has supported experiments for the Apollo space program, the space shuttle, and the International Space Station. Among the first tests ever conducted were fluid physics experiments supporting the Apollo space program.

At NASA's Johnson Space Center, the C–9 Reduced Gravity Aircraft is a modified two-engine turbojet used to train astronauts and conduct microgravity research. As NASA's lead center for microgravity research in the areas of fluid physics and combustion, Glenn houses the C–9 for 5 to 8 weeks each year in support of its ground-based microgravity research. This aircraft flies parabolas to create approximately 20 seconds of weightlessness for astronauts and researchers to investigate the effects of "zero" gravity. A typical mission is 2 to 3 hours long and consists of 30 to 50 parabolas.

Zero Gravity Research Facility (Zero-G)

The Zero-G Research Facility is the largest facility of its kind in the world and continues to be the nation's most modern research tool for exploring weight,lessness, or microgravity, here on Earth.

The Zero-G is NASA's premier facility for conducting ground-based microgravity research. Operational since 1966, it is one of two drop towers located at the NASA GRC. The facility was built during the Space Race Era of the 1960s and was originally built to support research and development of space flight components and fluid systems, in a weightless or microgravity environment. Today, the facility is used by investigators from around the world to study the effects of microgravity on physical phenomena such as combustion, fluid physics, biotechnology, and materials science.

Microgravity, a condition of relative near weightlessness, can only be achieved on Earth by putting an object in a state of free fall. In the Zero-G, experiments free fall 132 m and are weightless for 5.18 sec during the fall. The free fall is conducted inside of a 143-m steel vacuum chamber. Evacuating the chamber to a pressure of 0.01 torr reduces the acceleration, due to aerodynamic drag, on the freely falling experiment vehicle to less than 0.00001 g.

A variety of tests are performed in the Zero-G including

- Fundamental scientific studies of combustion, fluid physics, biotechnology, and material science
- Feasibility of experiment concepts proposed for long-duration microgravity experiments
- Development and testing of space shuttle and International Space Station experiment hardware
- Deployment of hardware during free fall in a vacuum environment

NASA GRC plays a major role in planning, directing, and implementing space experiments in technology and microgravity science. The Zero-G allows experimenters to quickly perform microgravity research, test space experiment concepts, and develop space flight hardware at a small fraction of the cost of conducting these tests in space.

Zero-G free-fall drop

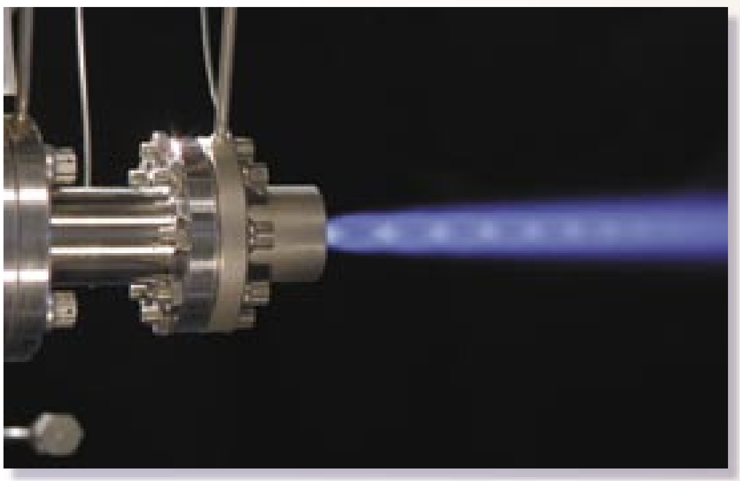
Steel vacuum test chamber

Chemical Propulsion and Propellant Handling

Chemical propulsion has provided the heavy lifting required for NASA to travel into space. Whether it is to reach Earth orbit, to escape the gravitational pull of the Moon, or to lift a manned vehicle into low Earth orbit, chemical propulsion has provided the thrust required. As NASA pursues new space exploration initiatives, the development of new technologies are required. Propellants with higher energy densities, zero cryogenic propellant boiloff for extended interplanetary missions, production of in situ propellants for return trips from Mars, materials that can endure high temperatures with less weight, and demonstration of chemical rockets under deep space conditions are just a sampling of the issues that GRC's personnel and facilities are prepared to address. Detailed facility test capabilities information is available on pages 44 and 45.

The Spacecraft Propulsion Research Facility (B–2) offers a complete "test-as-you-fly" environment to thoroughly ground-test flight hardware and reduce the likelihood of costly in-flight failures.

The Research Combustion Laboratory (RCL) and the Cryogenic Test Complex (CTC) have been influential in supporting the space industry by collaborating with NASA and engine research partners to develop and research safer propellants for future space missions.



Subscale concept development (RCL)

Cryocooler subsystem test (SMiRF)

Full-scale testing (B–2)

Large-scale cryogenic propellant test

Spacecraft Propulsion Research Facility (B–2)

The B–2 offers a complete "test-as-you-fly" environment to thoroughly ground test flight hardware and reduce the likelihood of costly in-flight failures.

NASA's B–2 is the world's only facility capable of testing full-scale upper-stage launch vehicles and rocket engines under simulated high-altitude conditions. The engines or vehicle can be exposed for indefinite periods to low ambient pressures, low background temperatures, and dynamic solar heating, simulating the environment the hardware will encounter during orbital or interplanetary travel. Vehicle new engine systems producing up to 100 000 lb of thrust can be fired for either single or multiple burn missions, utilizing either cryogenic or storable fuels or oxidizers. The facility infrastructure is capable of being modified to test engine systems that can produce 400 000 lb of thrust. Engine exhaust conditions can be controlled to simulate a launch ascent profile. In addition, altitude conditions can be maintained before, during, and after the test firing.

B–2 also serves as a stand-alone thermal/vacuum test facility. It represents the Agency's third largest space environment simulation test facility and as such has been used to test a variety of large space hardware. The versatile 38- by 62-ft chamber provides a maximum test specimen envelope of 24 feet in diameter and 50 feet in height. It is capable of maintaining 10^{-7} Torr pressures using ten 35-in. diffusion pumps backed by Roots blowers and Stokes mechanical pumps. A copper cryoshroud lines the inner surfaces of the chamber and provides 1.2 MW of heat rejection. Convenient access to the chamber is through a 27-foot diameter top port, along with two personnel doors at lower levels in the facility.

B–2 has performed tests on equipment such as small research engines, high-altitude balloon payloads, Mars rover airbag balloon landing and deployment systems, and spacecraft photovoltaic arrays. The B–2 facility is located at NASA's Plum Brook Station in Sandusky, Ohio.

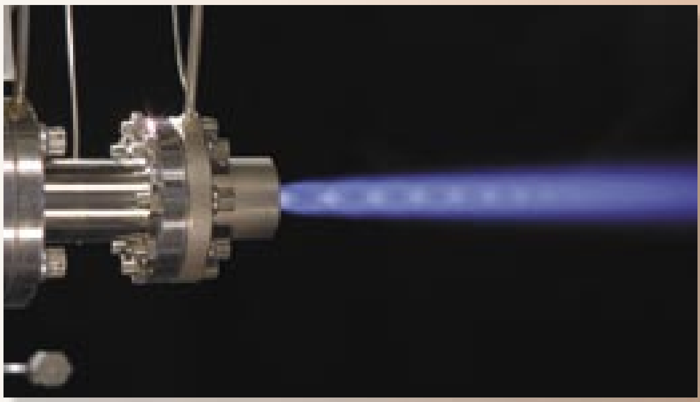
McDonnell Douglas Delta 3 Rocket Engine test

Flight solar panel test

Research Combustion Laboratory (RCL)

The RCL develops advanced propulsion concepts and evaluates safer propellants for launch vehicles and spacecraft thrusters and advanced ignition systems for next-generation launch vehicles.

The RCL consists of a suite of flexible test cells, including five sea-level combustion stands, two altitude combustion stands, the *Heated Tube Facility* (HTF) for studying heat transfer properties of fuels, an aircraft combustor test stand, and two test cells for studying advanced fuel cells. The RCL provides a safe environment for testing aviation and chemical rocket propellants, including liquid and gaseous hydrogen, liquid and gaseous oxygen, kerosene-based fuels, and hydroxylammonium-nitrate (HAN)-based monopropellants.



RCL flametube

Cooled-panel nozzle extension test

Research performed in the RCL can be divided into three main areas: fuels, ignition and combustion methods, and high-temperature materials. A variety of tests are performed in the RCL including altitude testing, chemical rocket ignition systems, high-temperature thermal testing, sea-level testing of chemical rocket engine components, clean-burning aircraft combustors, fuel cell and electrolyzer components, regenerative fuel cell systems, and heat transfer. The RCL's full spectrum of capabilities has made it the vanguard of innovations in developing advanced propulsion concepts. The RCL has evaluated safer propellants for space shuttle thrusters, ignition systems for next-generation launch vehicles, and lightweight high-temperature materials for aeronautics and space applications.

Cryocooler preparation for zero boiloff test (SMiRF)

The *Small Multi-Purpose Research Facility* (SMiRF), also part of the RCL, evaluates the performance of the thermal protection systems required to provide long-term storage (up to 10 years) of cryogenic propellants in space. SMiRF provides the ability to simulate space, high altitudes, and launch pressure environments; conduct calorimetry tests on prototype insulation systems; and safely handle gaseous and cryogenic propellants. The facility serves as a low-cost, small-scale screening facility for concept and component testing of a wide variety of hardware. SMiRF features a 72- by 100-in. diffusion-pumped high-vacuum chamber with a cold wall capable of simulating the thermal cycle of a lunar day. The facility's pumping system is augmented with mechanical pumps that are capable of matching a launch pressure profile. In addition to its vacuum capabilities, SMiRF has all the safety features including exclusion zones, remote control rooms, and propellant supply systems required to support testing of hazardous materials.

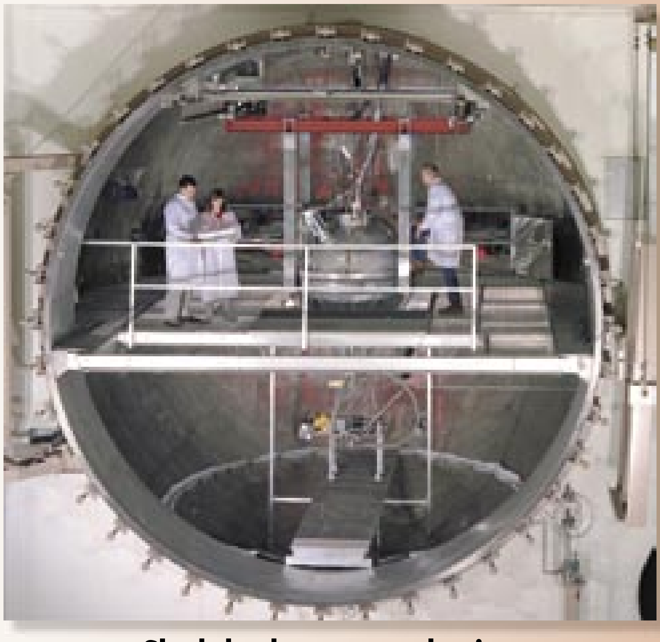
Cryogenic Test Complex (CTC)

The CTC supports research of cryogenic propellants and is a testbed for mechanical equipment with cryogenic propellants. Propellant densification and condition of cryogenic propellants is also a focus.

The CTC encompasses the vacuum chamber of the Cryogenic Propellant Tank Research Facility (K-Site), as well as a new state-of-the-art Cryogenic Component Laboratory (CCL) for research, development, and qualification of cryogenic materials, components, and systems. CTC buildings and systems are ideally suited for high-energy, high-risk research on cryogenic systems utilizing liquid hydrogen, oxygen, and nitrogen. Testing includes chilldown: seal, bearing, and turbopump tests; fluid densification; and thermal-vacuum testing of spacecraft subsystems, sensors, probes, tanks, and insulation. The CTC is located at Glenn Research Center's Plum Brook Station in Sandusky, Ohio.

Cryogenic Test Complex

The K-Site is a 25-ft-diameter high vacuum space environment test chamber with a 20-ft-diameter door. The design and construction of this facility allows large-scale liquid hydrogen (LH_2) experiments to be conducted safely. Control and data systems are located in a separate remote building, and electrical control systems include explosion-proof hardware. K-Site also features a removable LH_2/LN_2 cryogenic cold wall, which can simulate deep space temperatures down to –423 °F; vacuum-jacketed LH_2 piping and chamber penetrations; a hydraulic shaker system; and a vacuum-jacketed LH_2 dump line and burnoff stack to handle accidental LH_2 spills inside the chamber. K-Site plays an essential role in the development of advanced insulation systems and on-orbit fluid transfer techniques for flight-weight cryogenic fuel tanks and insulation systems. The facility also includes an 800-gal slush hydrogen batch production plant and a 200-gal small-scale propellant densification system.



Slush hydrogen production

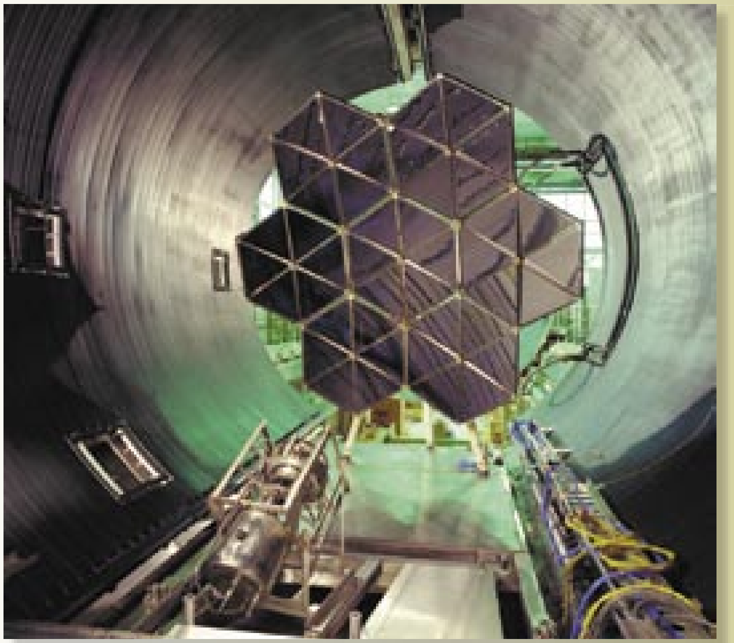
CCLs include test cells with extensive LH_2 and liquid oxygen (LOx) handling capabilities. Two test cells support small-scale testing of turbomachinery components such as bearings, seals, and related equipment under cryogenic operating conditions. Cell 1 is designed to provide LOx or LH_2 at conditions up to 1250 psig and 75 gpm by means of multiple-stage cryogenic pumps. The pumps are fed from a 3000-gal supply dewar. Cell 2 is designed to provide LH_2 from a 1300-gal dewar at pressures up to 1250 psi. The CCL also provides capabilities for the densification and conditioning of cryogenic propellants. All test activities at the CCL are conducted from a remote 7500-sq-ft control room equipped with high-speed data acquisition system. The CCL is supported by an extensive infrastructure of both liquid and gaseous storage of hydrogen, oxygen, nitrogen, and helium.

Electric Power and Propulsion

To fulfill the nation's desire to investigate the heavens and conduct operations in space, NASA must develop technologies that operate under the unique environment of space. Loss of atmosphere, temperature extremes, space plasma, and atomic oxygen degradation are just some of the unique attributes of space, which must be considered in the design and development of spacecraft. Glenn Research Center has a suite of facilities that are prepared to address these concerns, including the Space Power Facility (SPF), Electric Propulsion Laboratory (EPL), and the Electric Propulsion Research Building (EPRB).

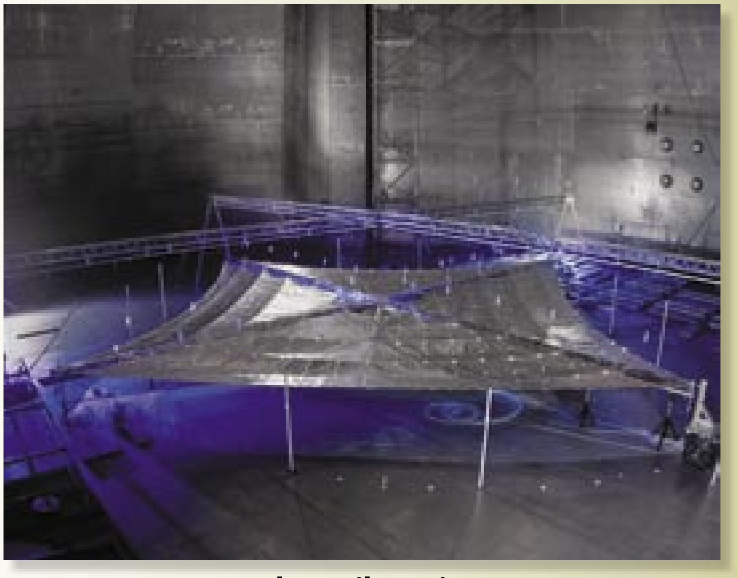
Although no facility can fully simulate all the conditions of space, Glenn's facilities can tackle challenges such as simulating the landing of a Mars rover; developing new power and propulsion technologies for interplanetary travel to destinations such as Mercury, the icy moons of Jupiter and Pluto; or qualifying an upper-stage thruster for delivering satellites into geosynchronous orbits by replicating specific attributes of space. Glenn maintains 23 thermal vacuum facilities with diameters greater than 3 feet. Thermal vacuum facilities principally focus on the space environmental effects from the loss of atmosphere and temperature extremes. *Detailed facility test capabilities information is available on page 46.*

Ion engine test



Solar concentrator testing

Hall thruster testing



Solar sail test in SPF

Electric Propulsion Laboratory (EPL)

The EPL develops and tests spacecraft power and propulsion technologies for space missions that enable NASA to conduct presently nonviable planetary missions and provide the space community with less costly, more effective orbital space missions.

The EPL features two very large space environment simulation chambers (VF–5 and VF–6); five intermediate simulation chambers that are suitable for testing small engines or components; several bell jars for development and testing of small-scale components; and support areas including an electronics shop, machine shop, clean room, and office space.

The EPL's space simulation chambers have been enhanced to support the unique requirements of electric propulsion and power system testing. VF–5 is the leading testbed for electric propulsion. VF–5's vacuum pumping system can pump condensible gases (3.5 million liters/sec) with its 33.5 m^2 of 12 K helium cryopanels or noncondensible gases (250 000 liters/sec) using baffled diffusion pumps.

VF–6 supports both power system and electric propulsion testing. A solar simulator provides 1.2 solar constants on a 5-m-diameter target or 11 solar constants on a 30-cm target with a low subtense angle specifically designed to support solar concentrator testing. Its 900 000 liter/sec pumping speed and 25 foot diameter by 70 foot length supports thruster wear testing because its large volume and high background vacuum minimizes backsputter and entrainment effects.

Several of the chambers have multiple air-locked access ports. These ports allow several tests to be conducted simultaneously in each chamber without cycling the chamber back to atmospheric pressure during introduction or removal of test hardware. Conditioned dc power is supplied to VF–5, VF–6, and VF–12 for powering ion, Hall, and magnetoplasmadynamic (MPD) thrusters. All EPL facilities run autonomously.

NEXT ion engine test

VF–6 solar simulator

VF–5 test chamber

Electric Propulsion Research Building (EPRB)

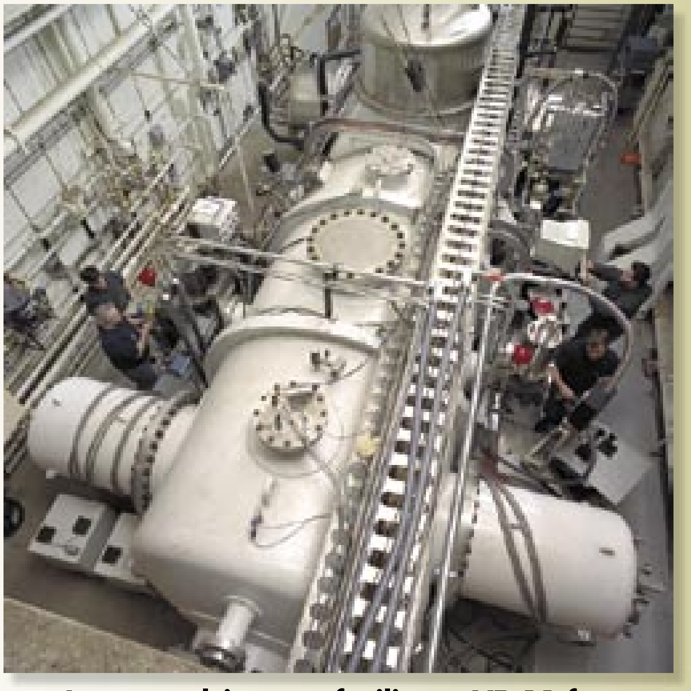
The EPRB works in synergy with NASA Glenn's world-class facilities by developing and validating electric propulsion technologies at the component and conceptual levels.

The research cornerstone of the EPRB is its suite of space simulation chambers. EPRB chambers, ranging in size from benchtop bell jars to 3-m-diameter tanks, are equipped with various pumping systems (cryopumps, diffusion pumps, oil-free pumping trains, and high-throughput Roots blowers), depending upon the specific requirements of a test program.

Facilities of particular note are the VF–11 and VF–16 ion engine testbeds; the VF–1 250-kJ capacitor bank, which is especially suited for conducting fundamental research on high-powered thrusters such as the MPD thruster; VF–9's capability to produce atomic oxygen; and VF–7, which is surrounded by 1-ft-thick concrete. VF–7 is an excellent testbed for conducting research where safety is a concern, such as research on thrusters using hydrogen as a propellant or thrusters that produce plasmas through radiofrequency generation.

In addition, EPRB has over 20 000 sq ft of specialty labs and buildup and machine shop areas. The EPRB works synergistically with other larger vacuum facilities located at Glenn. Research that is initiated in EPRB on the concept or component level often leads to higher fidelity tests in facilities such as VF–5 (very high pumping speed), VF–6 (unique in its solar simulator capabilities and electric propulsion features), or SPF (the world's largest vacuum chamber). This process ensures that these world-class facilities are effectively utilized and that research is done in the most cost-effective manner possible.

Thermal vacuum environmental testbed at VF–10



Ion propulsion test facility at VF–11 for developmental tests

Space Power Facility (SPF)

SPF, the world's largest space environmental simulation chamber, provides the capability to test large spacecraft in a thermal vacuum environment. Due to its unique size and capabilities, SPF has frequently been the only viable test facility for not only national programs but also international customers.

The SPF houses a 100-ft diameter by 122-ft high thermal vacuum chamber. SPF was designed and constructed to test both nuclear and nonnuclear space hardware in a simulated space environment; however, only nonnuclear tests have been performed throughout its history. The vacuum chamber can sustain high vacuum (10^{-6} torr) with either ten 48-inch diameter cryopumps with vacuum isolation valves or sixteen 48-inch diffusion pumps with liquid-nitrogen-cooled-baffles. The thermal environment can be provided with test-specific cold walls, fed by either liquid nitrogen or by a variable temperature (250 °F to ambient) gaseous nitrogen recirculating system; a 4-MW quartz heat lamp array; and a 400-kW solar arc lamp.

SPF's ability to handle large equipment is supported by a 20-ton crane installed inside the vacuum chamber, two adjacent 150- by 75-ft high bay areas augmented with 25-ton bridge cranes, and two 50- by 50-ft doors leading directly into the chamber from the individual high bay areas. The chamber floor is designed to withstand a load of 300 tons.

As a result of its size, SPF has been the facility of choice for several test programs, including high-energy experiments, rocket-faring separation tests, Mars lander system tests, and International Space Station hardware tests. The SPF is located at NASA Glenn's Plum Brook Station in Sandusky, Ohio.

Boeing Delta IV payload fairing test

ISS radiator deployment test

Mars exploration rover landing system test

Power Systems Facility (PSF)

The PSF provides an exceptional platform to not only test and verify today's space power systems, but also to design, develop, and test components and systems for new technologies.

The PSF supports the design, development, assembly, and testing of space power components and systems that include the International Space Station, satellites, next-generation launch vehicles, and space-based power systems. PSF houses testbeds where experienced scientists and engineers verify critical concepts, test prototype hardware and software, and validate systems in real-time simulations under actual loading and operating conditions. Testing capabilities include flywheel systems and components, battery systems, fuel cells, AC power sources, electrical actuators, and power management and distribution hardware and software. An adjacent solar array field provides 960 solar cell modules to power system hardware during testing.

PSF provides a 5000- sq-ft, Class 100 000 clean room. This 60-ft high bay test area is adjacent to another 5000-sq ft high bay area that is also clean room capable. A series of trenches provide the capability to easily connect the various test areas in PSF in order to support system-level testing of large power systems. Two test cells are surrounded by blast-resistant walls for supporting high-energy testing. An underground spin pit provides high-speed spin testing capability. A 1600-sq ft raised floor area provides a laboratory environment to support power management and distribution systems development.

The Telescience Support Center (TSC) is also located in PSF. The TSC is a facility that provides the capability to execute ground support operations of on-orbit ISS payloads and other space missions. TSC capabilities are provided in coordination with the Marshall Space Flight Center (MSFC) Payload Operations and Integration Center (POIC), the Johnson Space Center (JSC) Mission Control Center in Houston (MCC–H), and other remote ground control facilities.

Electric Propulsion Systems testbed

Telescience Support Center

Power Systems Facility high bay clean room

Fuel Cell Test Facilities

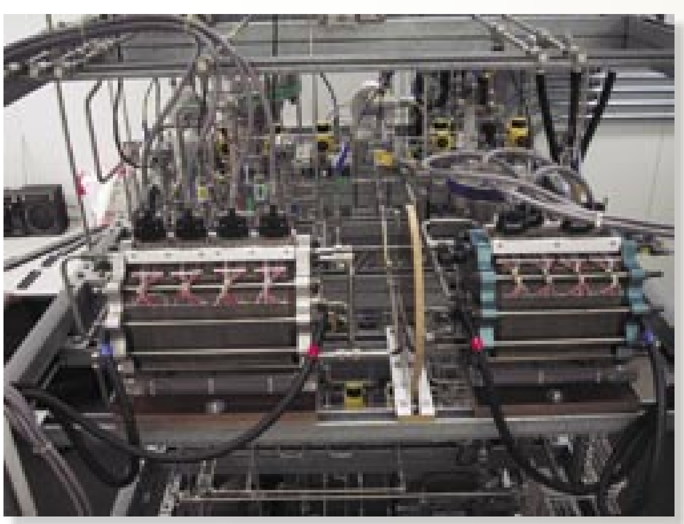
Several test laboratories at the GRC support fuel cell research for space and aeronautics applications. Research focuses primarily on hydrogen/oxygen and hydrogen/air fuel cells.

Fuel Cells Test Laboratory

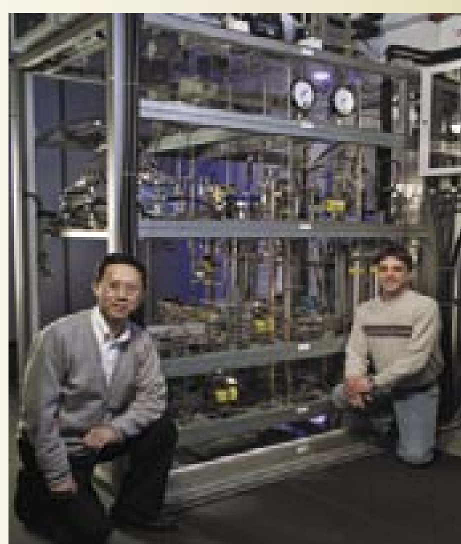
The Fuel Cells Test Laboratory, located in building 334, is the most recent addition to these capabilities. The building contains three test cells supplied with hydrogen, oxygen, and nitrogen gases from 2400 psig tube trailers. In addition, a compressed air system provides 190 psig air to support air/hydrogen fuel cell tests. The test cells are designed as class I, division 2 hazardous locations for hydrogen use, and are operated from a common remote control room. Each cell can support fuel cell tests at power levels up to 125 kW. Continuous, long-duration testing lasting for several days can be performed. A programmable logic controller (PLC)-based control system monitors and controls test operation, and a LabView®-based data acquisition system records system parameters several times per second.

Building 334 Control Room

The Regenerative Fuel Cell test rig, located in building 135, is a closed-loop system designed to study energy storage and power generation using an electrolyzer to generate hydrogen and oxygen from water and a fuel cell to recombine the gases and generate power. Applications might ultimately include high-altitude, solar-powered aircraft for Earth observation, reconnaissance, and telecommunications. The facility has the capability to simulate complete day/night power cycles with a 5-kW hydrogen/oxygen PEM (proton exchange membrane) fuel cell and a 15-kW PEM electrolyzer. Supporting tests for fuel cell and electrolyzer components used in the regenerative rig are conducted in cell 24C of the Research Combustion Laboratory (RCL).



Fuel Cell and Electrolyzer in Regenerative Fuel Cell Rig



Regenerative Fuel Cell Test Rig

Research and Technology Laboratories

Research and Technology laboratories support a wide range of NASA GRC research and development testing. This section only highlights a few of the areas in materials, structures, communications, and instrumentation and controls.

Materials

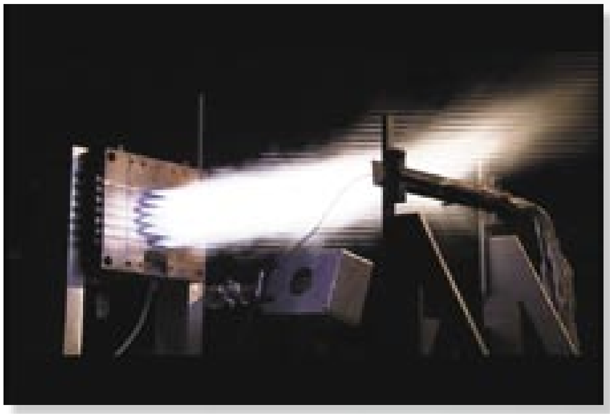
Glenn's materials facilities provide capabilities for research and development of advanced high-temperature materials and processes in the areas of superalloys, intermetallics, refractory alloys, metal matrix composites; ceramics, ceramic matrix composites, nanotechnology, high-temperature piezoelectric and solid-oxide fuel cell materials; polymers, adhesives, aerogels and polymer matrix composites; and high-temperature chemistry, durability testing, and protective coatings. Research capabilities include processing, testing, characterization, and computer modeling of materials and processes.

The Advanced Metallics Branch conducts basic and applied research and advanced development of metal alloys, intermetallic compounds, and metal matrix composites. Research is focused on understanding the interrelationships among processing, nanostructure and microstructure, and processing as they pertain to component performance. Branch facilities support advanced processing, alloy modifications, and computer modeling for accelerated development of materials. Specific examples include various alloy melting and solidification furnaces, hot presses, hot isostatic press, welding, heat treating, tensile, creep, and fatigue test facilities.

The Ceramics Branch conducts basic and applied research and advanced development in the areas of synthesis, processing, prediction of mechanical and physical behavior, and life prediction of structural composites and functional ceramics such as piezoelectrics and solid-oxide fuel cell materials. Branch facilities support the fabrication, characterization, and study of structural and physical properties of ceramic materials. Examples include ceramic processing labs, laser float zone fiber growth rigs, fiber testing facilities, and a rocket test facility.

The Polymers Branch conducts basic and applied research and advanced development in the areas of synthesis, processing, and characterization of polymers, adhesives, nanocomposites, aerogels, and polymer matrix composites. Branch facilities support computer modeling of polymers and polymer matrix composites. Examples include prepreg winders, presses, autoclaves, tensile test machines, acousto-ultrasonic evaluation, a spectroscopy lab, an atomic force microscope, nuclear magnetic resonance facilities, and analytical chemistry laboratories.

The Durability and Protective Coatings Branch conducts basic and applied research on the behavior of advanced materials exposed to high temperatures, pressures, gaseous environments, and velocities. Facilities support modeling of degradation processes and verification of life-prediction methodologies. State-of-the-art thermal and environmental barrier coatings are developed and assessed for long-term durability. Selected examples include laser labs, burner rigs, physical and chemical vapor deposition facilities, a mass spectroscopy lab, and a plasma spray facility.



Quick Access Rocket Exhaust (QARE) rig low-cost testing for screening advanced rocket engine materials

Mach 0.3 burner rig evaluating a thermal/ environmental barrier coating on a silicon nitride vane

Structures

Structures research facilities support development of enabling structural, and mechanical system and mechanism concepts and advanced technologies for current and future propulsion and power systems. Development of validated analytical, computational, and experimental technologies for materials, structures, and mechanical systems helps assure integrity, durability, and reliability of aerospace propulsion and power systems. Structures test facilities cover a range of technical disciplines including life evaluation, material and structural mechanics including dynamics and aeroelasticity, drive systems, seals, advanced bearings, solid and liquid lubrication, and surface science. These technologies are applied to aircraft, launch systems, spacecraft, and ground vehicles.

Communications Technology

Communications facilities provide capabilities for research and development of advanced space and aeronautical communication concepts, architectures, components and systems. Advanced research and technology development enables new capabilities for robust, mobile, high data rate links between spacecraft, aircraft, satellites, and Earth stations. Test facilities and research laboratories for modeling, simulation, design, development, and testing of end-to-end communications systems and networks are available including microwave antenna characterization, high-power traveling wave tube amplifiers, software-defined radios, mobile networking, radiofrequency propagation, cryogenic microwave electronics, secure digital data links, and communication satellite Earth stations.

Ballistic impact test of space shuttle foam insulation

Instrumentation and Controls

Glenn conducts basic and applied research on advanced instrumentation and controls technologies for aerospace propulsion and power applications. Advanced research to enable intelligent systems for aerospace applications includes harsh environment sensors; high-temperature, high-power electronics; microelectromechanical and nanoelectromechanical systems; high-data-rate optical instrumentation; active and intelligent control; and health monitoring, diagnostics, and management. These research areas address Agency challenges to develop aerospace systems with reduced size and weight, and increased functionality and intelligence for future NASA missions in aeronautics; economical space transportation; and pioneering space exploration.

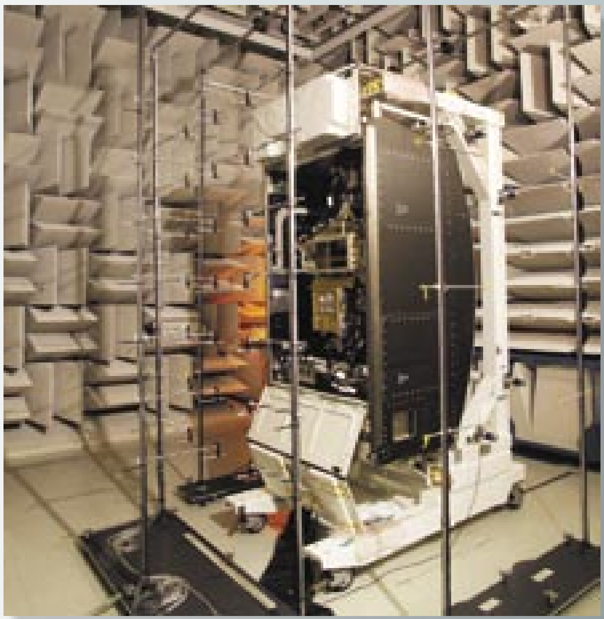
Deep reactive ion etching tool for micromachining of SiC in class 100 cleanroom

4 × 6 Meter Inflatable Membrane Antennae test in the Near-Field Antenna test facility

Development and Verification Laboratories

Several environmental laboratories provide developmental and verification testing to help developers of space flight hardware meet NASA's requirements that limit emissions and susceptibility to acoustic, structural, and electronic interference.

The Acoustical Testing Laboratory (ATL) provides acoustic emission testing and low-noise design services, particularly for space flight hardware that must meet NASA's acoustic emission requirements. A convertible hemianechoic test chamber has interior dimensions of 21 by 17 by 17 ft (high) in anechoic configuration, which provides an ideal environment for developmental testing on small noise source components as well as full-scale verification testing of flight hardware. The ATL's data acquisition system provides real-time one-third octave band and FFT measurements as well as a variety of specialized diagnostic techniques, including scanning sound intensity. The ATL is accredited by the National Institute of Standards and Technology.



Acoustical Testing Laboratory

The Structural Dynamics Laboratory (SDL) performs structural dynamic testing to verify the survivability of a component or assembly when exposed to vibration stress screening or a controlled simulation of the actual flight or service vibration environment. Environmental stress screening, or workmanship vibration, is used to identify latent manufacturing defects of components prior to being incorporated into larger assemblies. Vibration testing is also used to verify design margins of assemblies and characterize the internal dynamic responses of a test article.

Fluids and Combustion Facility Combustion Integrated Rack, Ground Integration Unit, Modal Test in SDL

The Microgravity Emissions Laboratory (MEL) provides testing support for simulation and verification of the International Space Station microgravity environment. The MEL utilizes a low-frequency acceleration measurement system for the characterization of rigid body inertial forces generated by various operating components of the International Space Station (ISS). The facility is unique in that 6-degrees-of-freedom inertial forces can simultaneously be characterized for operating the test article. Vibratory disturbance levels can be measured for engineering or flight-level hardware.

The Electromagnetic Interference (EMI) Laboratory offers several services including analysis of hardware requirements and specification comparisons, consultation during the design and prefabrication phases, electronic component testing, specialized test procedures for unique hardware requirements, intermediate testing as the design progresses, testing of materials for shielding effectiveness, frequency response tests of networks and filters, final qualification testing of experiments in flight configuration, and testing at customer locations for items too large to fit in the EMI Laboratory's shield rooms.

Structural testing is performed to verify the structural integrity of space flight and ground test hardware. Testing in the Structural Static Laboratory (SSL) is also performed to verify the finite element analysis by measuring stiffness and induced stress at points in a test article. A structural test can be used to verify the modes of failure of a design when exposed to simulated service loads.

Information Technology Laboratories

Information Technology Laboratories are developing new ways for researcher's to acquire, explore, and analyze data.

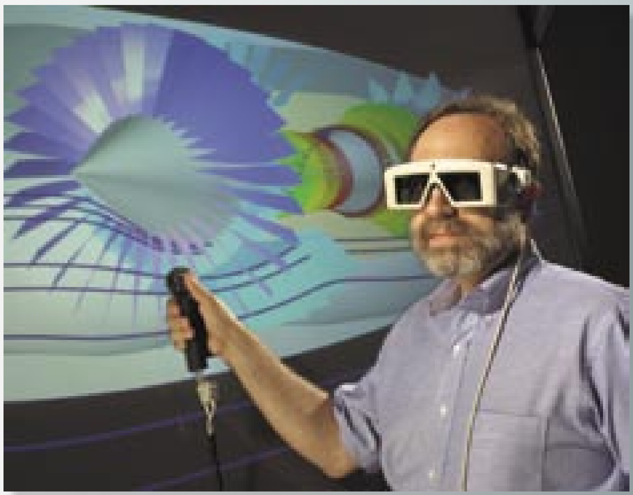
Glenn's Graphic and VISualization (G–VIS) and Glenn Reconfigurable User-interface and Virtual-reality Exploration (GRUVE) laboratories:

The G–VIS and GRUVE laboratories are companion facilities that provide advanced computer imaging and scientific visualization services to the NASA research community. The G–VIS lab specializes in developing custom data visualization techniques and houses the latest computer graphics and multimedia technologies. The GRUVE lab is built around a reconfigurable, fully immersive walk-in virtual reality facility consisting of three large 8- by 8-ft rear-projection screens on which are displayed computer-generated stereoscopic images. Special sensors and I/O devices allow the user to fully interact with objects in the virtual environment. Both custom-designed and commercial software provide a wide array of applications to NASA scientists and engineers.

GRUVE laboratory

The G–VIS/GRUVE labs are used predominantly for analysis of data obtained either by computer simulation or from one of NASA Glenn's research test facilities. The advanced visualization and interactive technologies enable greater understanding and insight into the complex relationships among the data than do the typical tools available at the desktop. In addition, the virtual reality environment supports simulations of exotic environments and phenomena not otherwise possible. Some of these applications include

- Fully immersive inspection of complex flows in jet engine combustors and inlets
- Simulation of the appearance and behavior of smoke in a microgravity habitat for fire detection and visibility studies
- Interfacing a virtual reality display with advanced treadmill and exercise equipment as a countermeasure for disorientation on long-duration space flights



G–VIS laboratory

The Advanced Computational Concepts Laboratory (ACCL) is a flexible, application-oriented testbed environment for exploring emerging network and computing architectures as well as techniques, which could enhance future NASA GRC production capabilities. Current research examines parallel and distributed processing, interprocessor communication via advanced networks and switches, and the development of workstation clusters as low-cost alternatives to conventional supercomputing.

Facility Test Capabilities

Central Process System (CPS)

The CPS provides the required pressurized air and exhaust services from two equipment buildings via a complex piping network to the aeropropulsion facilities. The equipment used to create the air pressures, flows, and conditions includes motor-driven compressors, exhausters, turboexpanders, chillers, air dehydrators, cooling tower systems, and various other types of support equipment. The CPS distributes 300 000 hp of energy through over 23 000 ft of piping to the more than 100 test cells located throughout GRC.


Central air equipment building

Operators utilizing the state-of-the-art Central Process-Distributed Control System (CP–DCS) monitor and control all the systems within the CPS including the high-voltage substations and variable frequency drive systems. Central Control and equipment building staff precisely regulate and monitor the delivery of air services to the test cells where test cell operators fine tune the flows to meet the requirements. The configuration of the CPS allows for a tremendous amount of flexibility and quick response to the changing requirements and customer needs.

System	Building	
	Engine Research	Central Air Equipment
10-psig refrigerated air	One 75-lb/s turboexpander, –70 °F outlet temperature	Three 133-lb/s turboexpander, –90 °F outlet temperature
40-psig combustion air	Two 38-lb/s compressors	Four 120-lb/s compressors
125-psig shop air service	Four 3-lb/s compressors	————
150-psig combustion air	Two 38-lb/s compressors	Two 192-lb/s compressors
450-psig combustion air	Two 38-lb/s compressors	One 38-lb/s compressor
1250-psig combustion air	One 38-lb/s compressor	————
Altitude exhaust	————	Eight exhausters with flow rates of 520 to 220-lb/s at pressures of 900 to 100 psfa (55 000 ft max. altitude)
Atmospheric exhaust	Two 69 000-cfm blower fans at 8-in. water	————

Aeronautics Facility Test Capabilities

Engine Components

AAPL

Capabilities	Nozzle Acoustic Test Rig (NATR)	Short Hot Jet Acoustic Rig (SHJAR)
Free-jet tunnel speed, Mach	0.35	N/A
Tunnel diameter, in.	53	N/A
Nozzle pressure ratio, max.	4.5	8.0
Nozzle exhaust temperature, max.	1425 °F	1300 °F
Thrust measurement, max.	2000 lbf	100 lbf
Fuels	Natural gas	Gaseous H_2
Compressed air services		
150 psig	130 lbm/sec	6.0 lbm/sec
450 psig	30 lbm/sec (heated)	N/A

ERB, ASCR, and ECRL

Combustor Facilities					
Facility	**Test emphasis**	**Max. pressure, psig**	**Max. airflow, lb/sec**	**Nonvitiated heated air, °F**	**Max. exhaust temp., °F**
CE–5B	Sector	60 to 275	2 to 12	500 to 1350	3200
CE–5B–2	Flametube	60 to 400	0.6 to 5	500 to 1350	3200
CE–9B–A	Sector	120 to 450	5 to 30	750 to 1100	3400
CE–9B–B	Flametube	120 to 450	1 to 15	750 to 1100	3400
ASCR Leg 1	Sector	50 to 900	3 to 50	500 to 1200	3400
ASCR Leg 2	Flametube	50 to 900	1 to 10	500 to 1200	3400
ECRL–1B	Augmentors	5 to 150	5 to 60	100 to 625	1900
RCL	Flametube	0 to 350	0.5 to 4	500 to 1200	3000

Compressor Facilities				
Testing Parameters	**W–1A Low-Speed Compressor Facility**	**W–7 Multistage Compressor/ Fan Facility**	**W–8 Single-Stage Axial Compressor Facility**	**CE–18 Small Engine Components Compressor Facility**
Inlet air pressure	Atmospheric	atm to 20 psig	5 to 20 psia	2 to 40 psia
Inlet air temp.	Ambient	–30 to 100 °F	Ambient	–20 to ambient
Inlet airflow	66 to 32 lb/s	95 lb/s	100 lb/s max.	60 lb/s
atm exhaust	0.8 psid blowers	0.8 psid	0.8 psid blowers	14.7 psid
Alt. exhaust	20 to 26 in. Hg	26 in. Hg vacuum	26 in. Hg vacuum	20 to 26 in. Hg
Rotor speed	1920 to 1050 rpm	18 756 rpm	20 600 rpm max.	60 000 rpm max.
Rotor size	60 to 48 in.	20 to 22 in.	20 in.	8 to 20 in.
Drive motor	1500 hp	15 000 hp	7000 hp max	6000 hp

Aeronautics Facility Test Capabilities

Engine

PSL and ECRL

Capabilities	Propulsion Systems Laboratory	Engine Components Research Laboratory Cell 2B
Test cell size	24 diam. by 39 liter ft	Cell 60- by 25-ft wide Chamber 6- by 6-ft wide
Simulated altitude	5000 to 90 000 ft	5000 to 45 000 ft or ground level
Simulated flight speed Mach no. PSL–3 PSL–4 PSL–4 (free jet with heater)	Mach no. to 3.0 to 4.0 to 6.0	1.6 (theoretical)
Maximum inlet mass flow PSL–3 and PSL–4 (at 55 psia) PSL–4	 480 lbm/s 380 lbm/s	12 lbm/sec
Inlet total temperature PSL–3 PSL–4	 –60 to 600 °F –90 to 1100 °F	Ambient
Maximum exhaust mass flow	750 lbm/s	35 lbm/s
Core testing capability 180 psia 425 psia 425 psi 465 psi	 25 lbm/s at 1375 °F 10 lbm/s at 1100 °F 73 lbm/s at 450 °F 39 lbm/s at 1200 °F	
Cooling air (mass flow) 100 lb/s	55, 165, and 450 psia	5 lbm/sec at 150 psig 3 lbm/sec at 450 psig
Thrust measurement Axial Vertical Lateral	 50 000 lbf 15 000 lbf 15 000 lbf	600 ft lb at 21 000 rpm
Fuel systems	Jet A, JP–4, JP–5, or JP–8 Hydrogen	Jet A, JP–4, JP–5, or JP–8 Hydrogen
Fuel flow rate at 65 psia	200 gpm	5 gpm at 40 psig

Wind Tunnels—IRT

Test section dimensions, ft Height Width Length	 6 9 20
Liquid water content, LWC, g/m^3	0.2 to 3.0
Drop size, MVD, μm	15 to 50
Uniform icing cloud dimensions, ft	4.5 by 6
Cloud uniformity, percent LWC	±20
Test section air velocity, KTS	50 to 350
Test section total temperature, ˚C	–30 to 40
Simulated engine flow lb/sec	1 to 85
Heated auxiliary air (bleed simulation) (at 900 ˚F and 120 psig), lb	1

Propulsion Wind Tunnels—10×10, 9×15, 8×6, 1×1, and HTF

	10×10 Supersonic		9×15 Low Speed	8×6 Supersonic	1×1 Supersonic	HTF Hypersonic
	Prop. Cycle	Aero Cycle				
Test section speed, Mach	2.0 to 3.5 and 0 to 0.036		0 to175 mph	0.25 to 2.0 and 0.0 to 0.1	1.3,1.6, 2.0, 2.5, 2.8, 3.0, 3.5, 4.0, 5.0, 5.5, 6.0	5,6,7
Simulated alt., ft	57 000 to 77 000	50 000 to 150 000	Sea level	1000 to 35 000	11 000 to 115 00	68 000 to 120 000
Test section Reynolds no./per ft.	2.1×10^6 to 2.7×10^6	0.12×10^6 to 3.4×10^6	0 to 1.4×10^6	3.6×10^6 to 4.8×10^6	0.4×10^6 to 16.5×10^6	0.97×10^6 to 2.3×10^6
Dynamic pressure, lbf/ft^2	500 to 600	20 to 720	0 to 72	200 to 1340	80 to 1750	300 to 2200
Test section total temperature, ˚R	520 to 1140	540 to 750	Ambient to 550	520 to 720	520 to 1100	2200 to 4190
Auxiliary air supply At 40 psig At 150 psig At 450 psig Model exhaust	 —— 2 lb/s 12 lb/s 20 lb/s at 2 psia	 —— 2 lb/s 12 lb/s 20 lb/s at 2 psia	(Heated) 30 lbm/s 30 lbm/s 30 lbm/s variable	 30 lbm/s 30 lbm/s 30 lbm/s variable	 —— 2 lbm/s 8 lbm/s ——	——
High-pressure air storage at 2600 psig, scf	981 000	981 000	981 000	——	——	675 000 GN_2 at 45 000 psi 386 000 GO_2 at 22 000 psi
Fuels	Liquid jet fuel Gaseous H_2 and O_2			Gaseous Hydrogen	——	Liquid jet fuel Gaseous H_2 and O_2 Natural gas

Flight Research—Two Learjets, Twin Otter, S–3B Viking

Two Learjets Models 23 and 25	
Maximum takeoff weight	15 000 lb
Crew	2 pilots
Researchers	Up to 5
Range	More than 1000 nm
Cruise speed	350 KIAS/0.82 Mach
Certified altitude	45 000 ft/50 000 (Lear 25)
Engines	General Electric CJ 610–6 turbojet

DeHaviland DHC–6 Twin Otter Aircraft	
Type	STOL turboprop regional airliner and utility transport
Wingspan	65 ft
Length	49 ft 6 in. (with boom 60 ft)
Height	19 ft 6 in.
Weight	Max. takeoff: 11 000 lb
Performance	Max. cruising speed: 140 knots of indicated air space
Range with maximum fuel	300 nm
Cabin area	384 cu ft
Cargo door size	56 by 50 in.
Equipment racks	17.75 in. width, 28.75 in. height, and 22 in. depth
Load limits	120 lb and 2160 in.-lb measured from the base of the rack
Power	Limited to 35 A of 28 dc and 15 A of 400 Hz 115 V ac and 60 Hz 115 V ac

S–3B Viking Aircraft	
Propulsion	Two General Electric TF–34–GE–400B high bypass turbofan engines (9275 lb of thrust each). Common variants of this engine include the TF–34–GE–100 used in the A–10 Thunderbolt and a commercial variant used in a civilian aircraft called the CF–34
APU	Available for in-flight use up to 30 000 ft; provides 45-kVA electrical power and powers an electrical emergency hydraulic pump capable of supporting all hydraulic systems
Wingspan	68 ft 8 in.
Height	22 ft 9 in.
Length	53 ft 4 in.
Landing distances	Normal (20 °C) 3300 ft
Maximum effort	(20 °C) 2150 ft
Arresting gear	200 ft
Crew	Four
Current base weight	28 500 lb
Maximum design gross takeoff weight	52 539 lb
Maximum landing weight	45 900 lb
Fuel dump capability	9000 lb
Payload	Approximately 111 knots landing
Altitude	40 000 ft
Hard points	Two wing stations capable of carrying 2000 lb Two bomb bays with four stations capable of carrying 850 lb each
Range (no wind)	More than 2300 nm with drop tanks and 1850 nm with no drop tanks

Space Facility Test Capabilities

Microgravity

2.2 Drop Tower, C–9 Reduced-Gravity Aircraft, and Zero Gravity

Capabilities	**2.2 Drop Tower**	**C–9**	**Zero Gravity**
Microgravity duration	2.2 sec	20 sec	5.18 sec
Free-fall distance	24 meters	N/A	132 meters
Gravitational acceleration	0.0001 g	+/- 0.01	<0.00001 g
Mean deceleration	15 g	1.5 g	35 g
Peak deceleration	15 to 30 g	2.5 g	65 g
Vacuum level	N/A	N/A	0.01 torr
Vacuum chamber length	N/A	N/A	143 meters
Vacuum chamber diameter	N/A	N/A	6 meters
Drop Vehicle Capabilities Payload diameter Payload height Payload weight	- - - 0.88 meters Up to 159 kg	- - - 2.0 meters 975 kg/m^2	Up to 1 meter Up to 1.6 meters Up to 455 kg
Number of tests per day	Up to 12	Up to 40 tests per flight	2

Space Facility Test Capabilities

Chemical Propulsion and Propellant Handling

RCL

Combustion and Cryogenics Space Facilities						
Propellants	RCL–11	RCL–21	RCL–22	RCL–24C	RCL–31/32	B135
Volume (scf)						
GH_2	70 000	140 000	140 000		70 000	
LH_2		16 lb				
GOx	70 000	60 000	60 000		60 000	
LOx	100 gal	50 lb			50 gal	
HC		8 gal			100 gal	
Ethanol	50 gal	8 gal			100 gal	
Supply Pressure, psi						
GH_2		2400	2400		2400	400
LH_2		1800			1800	
GOx		2400	2400		2400	400
LOx	1100	1800			1800	
HC		1000				
Ethanol		1000				
Maximum flow (lb/sec)						
GH_2	0.022	0.3	2.0	0.0045	3.0	0.0002
LH_2		0.25			1.0	
GOx	0.08	1.0	4.0	0.0023	4.0	0.0016
LOx		2			7	
HC						
Ethanol		0.1				
Cooling						
Volume, scf						
GH_2			140 000		70 000	
LH_2					200 gal	
Water, gal	100		1300		150 gal	
Supply pressure, psi						
GH_2			2400		2400	
LH_2					1800	
Water			1200		1500	
Maximum flow, lb/sec						
GH_2			1.5		1.5	
LH_2					1.5	
Water, gpm		50	300	2 (100 °C)	200	
Deionized water		No	Yes	Yes	No	
Other capabilities						
Max. thrust, lbf	50	300	2000		2000	
Altitude, ft	95 000				——	
NEC, haz atm	HAN; Xm46; chemical/material compatibility (fume hood)					

Space Facility Test Capabilities

Chemical Propulsion and Propellant Handling

RCL Continued

Test Cell	Features
Cell 11	Conducts performance and life tests in both steady-state, long-duration, and pulse modes. Instrumented or optically accessible hardware, two-color pyrometry for high-temperature measurement, and laser-based diagnostic systems (Rayleigh, Raman, LIF, color Schlieren)
RCL–21	Low-flow facility used to test ignition systems and subscale propulsion concepts and to study pulse detonation engine phenomena. Gaseous or liquid oxygen is used with fuels including hydrogen, methane, carbon monoxide, ethanol, liquid hydrocarbons, and gelled or metallized fuels.
RCL–22	Used for high-temperature thermal testing of advanced rocket engine materials. Capable of gaseous hydrogen and oxygen flows over a wide mixture ratio range. Water-cooled engine hardware provides various chamber pressures.
RCL–31 and RCL–32	Provide gaseous and liquid oxygen, hydrogen, and kerosene fuels to test stands. Test article cooling can utilize water, liquid hydrogen, or gaseous hydrogen. An adjacent room supports laser-based optical diagnostic equipment.
RCL–23	Flametube facility for evaluating aircraft engine combustor designs. Nonvitiated heated air is supplied to the test section inlet. Water cooling is provided to the test section, allowing hot section operating temperatures up to 3000 °F.
RCL–24C	Provides testing of fuel cell and electrolyzer components. Gaseous hydrogen and oxygen are supplied at controlled humidification levels ranging from zero to fully saturated.
B135	Conducts testing of a regenerative fuel cell system as an energy storage device. Waste heat from electrochemical reactions and fuel cell load are dissipated by forced air. It provides an exclusion zone and outdoor oxygen and hydrogen storage tanks. The control room is located 750 ft away via optical links.
CCL–7	Used as a low-cost small-scale screening facility for concept and component testing. Has the ability to perform propellant transfer and vent flow tests. Test operations are conducted from a remote control room.
Cell 23	The Fuel Cell Test Laboratory is equipped with three separate cells that have identical capabilities and is designed to test a variety of fuel cells ranging from 1 to 125 kW power output.

CTC

Capabilities
28 000-gal liquid oxygen storage capability
3000-gal liquid oxygen transfer capability at pressures up to 250 psig
50 gal per minute liquid oxygen flow capability at pressures up to 800 psig via dual centrifugal pumps
75 gal per minute liquid oxygen flow capability at pressures up to 1250 psig via twin piston reciprocating pump
42 000-gal liquid hydrogen storage capability
1300-gal liquid hydrogen transfer capability at pressures up to 1250 psig
13 000-gal liquid nitrogen storage capability
502 000 scf of high-pressure GN_2 storage with delivery rates up to 2.0 lbm/sec for driving pumps, turbines, and other equipment
110 000 scf of high-pressure GH_2 storage
140 000 scf of high-pressure GHe storage

Space Facility Test Capabilities

Electric Power and Propulsion

Vacuum Facilities—PSF, SPF, EPL, and EPRB

Vacuum facility	Dimensions (diam. by length)	Vacuum system	No load pressure, Torr	Pumping speed liter/sec, air	Features
VF–1	5 by15 ft long	(2) 35-in. ODP	3×10^{-7}	40 000	250 kJ, 30-kW, pulsed capacitor bank supporting high-power electric propulsion research
VF–2	3.5 by 7 ft long	Turbopump	1×10^{-6}	1950	
VF–3	5 by 15 ft long	(4) 35-in. ODP	4×10^{-7}	80 000	Multiple test ports
VF–4	5 by 15 ft long				
VF–5	15 by 60 ft long Access: 13 by 30 ft long	Cryopanel 750 W at 20 K, 40 m^2 of He surface Diffusion Pumps (20) 32-in. pumps, –50 °F traps	1×10^{-7}	3 500 000 (cryo) 250 000 ODP	Leading testbed for electric propulsion thrusters and multiple test ports including 6-ft test port
VF–6	25 by 70 ft long	(12) 54-in. nude cryotube	5×10^{-7}	900 000	Multirole facility supporting high-power electric propulsion performance/life testing, large-scale thermal vacuum tests, and solar simulation, 30-kW solar simulation, –196 °C/340 kW cold wall 10-ft test port
VF–7	10 by 15 ft long	(5) 35-in. diffusion pumps			Operation in 2005
VF–8	5 by 15 ft long	(4) 35-in. ODP	4×10^{-7}	120 000	Portable cold wall for thrusters, multiple test ports
VF–9	2 ft wide by 5 ft long by 8 ft high	Roots blower pumps	1×10^{-3}	3000 cfm	Atomic oxygen production
VF–10	40 by 60 in. long	Turbopump	8×10^{-7}	1950	Cold wall 35 in. diam. by 40 in. long Control: –250 to 300 °F or (–320 °F)
VF–11	7.25 by 27 ft long	(3) 48-in. cryotubs (4) 36-in. cryotubs	1×10^{-7}	270 000	EP thruster testbed
VF–12	10 by 30 ft Access: 10 ft by 16 ft	Cryopanels 350 W at 20 K panel temp.	8×10^{-8}	1000	Medium to high-power electric static thruster testbed. Full-performance characterization, diagnostics, and power suite available
VF–13	5 by 11.5 ft	20-in. cryopump and turbopump	4×10^{-7}	10 500	Rapid turnaround with valved pumping system
VF–14	22 by 22 by 36 in.	Turbopump	5×10^{-7}	1000	
VF–16	10 by 25 ft long	(10) 48-in. cryotubs	7×10^{-8}	500 000	Electrostatic propulsion test facility and supports long-duration testing
VF–61	40 by 60 in. long	36-in. cryotub	3.5×10^{-8}	30 000	Multiple test ports
VF–67	3.33 by 10 ft	20-in. cryotub	9×10^{-7}	10 000	Full LN_2 flooded thermal shroud
CW–19	7 by 10 ft	(2) 35-in ODP with dual baffles of LN_2 and water	5×10^{-7}	25 000	
PIF–H	71 by 72 in.	36-in. cryotub	1×10^{-6}	30 000	Space plasma test facility; thermal shroud available upon request
PIF–V	6 by 9.5 ft	(4) 10-in. ODP	5×10^{-7}	5300	Space plasma test facility
SMiRF	72 by 100 in.	(3) 10-in. ODP	8.5×10^{-6}	7000	Hazardous test capability, thermal shroud –250 to 190 °F; launch pressure profile of atm to 6 Torr in 2 min
VF–61		36-in. cryopump	3.5×10^{-8}	30 000	Multiple test ports
VF–67	3.33 by 10 ft	20-in. cryopump		10 000	Sterling testbed
*SPF	100 by 125 ft	(32) 48-in. ODP cryopump (FY03)	5×10^{-6}	1 400 000	World's largest vacuum chamber thermal simulation; large test article handling very low vibration environment
*B–2	38 by 62 ft	(10) 35-in. ODP	1×10^{-6}	495 000	Hot-firing thermal simulation; hazordous test capability, altitude simulation, and 27-ft test port
*K-Site	25 ft diam.	(4) 35-in. ODP	7×10^{-7}	150 000	Hazardous test capability and thermal shroud vibration testing

**Plum Brook Facilities*

Data Acquisition

NASA GRC uses state-of-the-art computing resources to support today's dynamically changing facilities' test requirements providing the highest quality data and support to ensure cost-effective testing.

Glenn has developed an integrated hardware and software system to support aeronautical facility test needs. This steady-state system, called Escort, provides real-time data acquisition, limit checking, analysis, and display. The facility system acquires, converts, analyzes, and displays steady-state data on graphical and alphanumeric displays with rates up to twice per second. The base functions of escort are

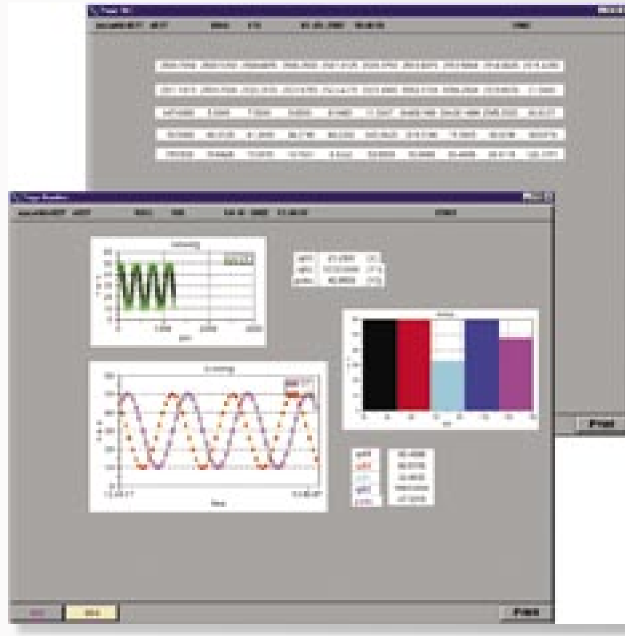
- Data acquisition of facility instrumentation (up to 2000 channels) that includes, but is not limited to, thermocouples, pressure transducers, force balances, speed pickups, accelerometers, positions, Electronically Scanned Pressure systems, as well as custom systems
- Real-time performance calculations (including iterative calculations) using sampled data
- Online real-time graphical and alphanumeric displays of all sampled and calculated parameters
- Integration with model controls to automate the test matrix to increase the rate of data capture
- Remote Escort data displays at the customer site are supported

Dynamic and Transient data is acquired with systems tuned to meet specific facility and test article needs. These systems vary from facility to facility. Systems range from less than a dozen channels to more than a hundred per system. Scan rates of a few hundred samples per second to millions of samples per second are supported. Industry standard as well as customer-specific data formats can be provided. Based on customer's requirements real-time displays can be generated. Acquired data can be transferred to the customer's computer and analyzed using their programs.

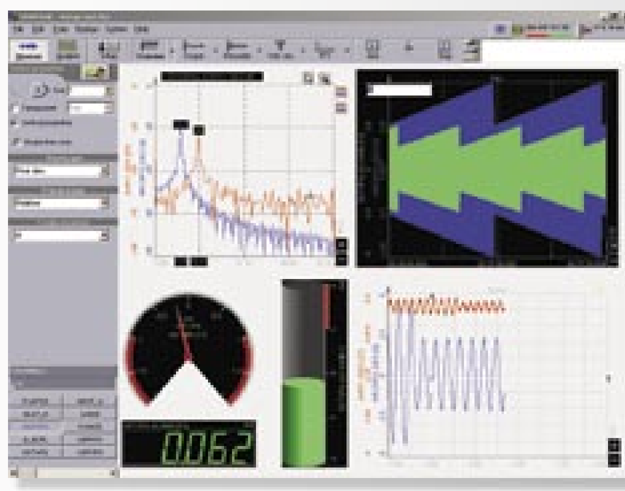
Imaging Services

Located onsite, the Imaging Technology Center (ITC) provides high-quality professional imaging services to Glenn's facilities and laboratories.

During a test, the ITC is available to provide high-speed and ultra-high-speed video and film-based services, thermal infrared imaging, high-definition and conventional video, and scientific photography. Other services include onsite photographic printing, CD/DVD authoring, file-format conversion, image analysis, and image archiving.



Steady-state data displays



Dynamic data displays

Imaging Technology Center

Doing Business With NASA Glenn

Our unique test facilities offer superior customer service and state-of-the-art testing capabilities. Test facilities are available for use by private industry, government, and academia. We are committed to providing the highest quality engineering, technical, and testing services at the lowest possible cost.

For additional information on NASA Glenn Research Center Test Facilities, visit the Web site: http://facilities.grc.nasa.gov/ or contact 216–433–5731.

The next steps summarize a typical test process at NASA GRC facilities:

1. Customers contact facility manager directly (contact list is provided below or call 216–433–5731. The facility manager is the primary point of contact for test facilities and will provide information about capabilities and the ability to support specific test requirements, scheduling, and cost.

2. Customers provide test requirements containing information such as test conditions, number of test runs, number of configurations, special instrumentation, and/or systems needed. To assist potential customers, a Test Request Form is available online at http://facilities.grc.nasa.gov/

3. Facility managers will coordinate with appropriate support organizations to assess test requests and provide customers with a cost estimate.

4. If test can be supported and customer is interested in pursuing test, then both parties will need to enter into a Space Act Agreement. The agreement will cover areas such as responsibilities, scheduling, and milestones, financial obligations, liabilities, and data rights.

5. A kickoff meeting and pretest meetings will be held as needed to coordinate the test requirements with the customer.

6. After test completion, actual test cost will be reconciled per Space Act Agreement.

Adhere **Facility Manager Contact List** here.

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National Aeronautics and
Space Administration

Glenn Research Center
Cleveland, Ohio 44135-3191

For additional testing information contact 216-433-5731